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PACKAGE PLANT CRITERIA DEVELOPMENT.
PART 1: EXTENDED AERATION

National Sanitation Foundation
Ann Arbor, Michigan

September 1966

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**PACKAGE SEWAGE TREATMENT PLANTS
CRITERIA DEVELOPMENT
PART I: EXTENDED AERATION**

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**PACKAGE PLANT CRITERIA DEVELOPMENT
PART I: EXTENDED AERATION**

**NATIONAL SANITATION FOUNDATION
ANN ARBOR, MICHIGAN**

**Dr. Henry F. Vaughan, President
Mr. Robert M. Brown, Vice President
Mr. Charles A. Farish, Executive Director**

**FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
DEMONSTRATION GRANT PROJECT**

WPD - 74

BRIAN L. GOODMAN, Project Director

September, 1966

1

Package sewage treatment plants

FOREWORD

the report

Package Sewage Treatment Plant Criteria Development - Part I: Extended Aeration summarizes the research which was conducted to establish a means by which the performance of ~~this type of~~ wastewater treatment device could be evaluated. ~~This~~ research effort resulted in the development of The Standard Performance Evaluation Method which is presented here. The evaluation method is based on the Performance Criteria which are also presented ~~in this report~~.

At the present time the research required for the establishment of performance evaluation criteria for contact stabilization package sewage treatment plants is being conducted. This research will be summarized and the criteria developed will be presented in Part II of this report which will be published in about a year.

It is the hope of the Foundation that the information contained in these reports will be used extensively by regulatory agencies, manufacturers, engineers, contractors, owners, operators, and all others concerned in the design, application, and operation of package sewage treatment plants. Further, it is hoped that such use of the findings presented here will result in a better understanding of the capabilities of this type of wastewater treatment device.

NATIONAL SANITATION FOUNDATION

September, 1966

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PACKAGE PLANT CRITERIA DEVELOPMENT

Part I: Extended Aeration

I. GENERAL

Fifty years ago Americans lived, generally, either on farms or in towns. Today, a third major area has developed which we call suburbia. During that fifty year period many other changes in the American way of life have taken place. The development of the automobile and the construction of superhighways have added the dimension of mobility to the American way of life. Tremendous population growth has taken place and many businesses and industries have followed the migration of a large segment of the population into suburbia both to serve these new areas and to escape the overcrowded cities. Further, as the population grew so did the problem of pollution until it became not only one of local significance but of national significance as well. Until the advent of suburbia and the era of mobility the collection and treatment of sewage involved either the use of conventional collection and treatment systems in the towns and cities or the use of individual disposal methods such as privies, cesspools, and septic tanks in the rural areas. Neither of these two basic methods were well suited for suburban use. Attempts to utilize the existing individual disposal methods largely were unsatisfactory in suburbia because of the limited amount of land available to the individual home owner and the variability of soil conditions. Further, as mobility increased the use of highway rest area facilities taxed the limited capabilities of existing waste disposal methods. What was clearly needed was a waste treatment and disposal system which was capable of achieving a relatively high level of treatment in connection with waste volumes intermediate between those of the cities and the farms. The so-called package treatment plant has been claimed by its developers to be the answer to this dilemma.

PREVIOUS STUDIES

The forerunners of today's package sewage treatment plants were in use in this country at least as early as 1934.¹ In 1947 aerobic digestion as a complete treatment process was brought to the attention of the Ohio Department of Health through the reports of the East Palestine (Ohio) Sewage Treatment Plant Superintendent.² Porges, Jasewicz, and Hoover proposed the total oxidation of influent organic substrate in a treatment

system as a result of their study of dairy waste treatment which was published in 1953.³ In 1958 McKinney *et al* reported on the design and operation of a completely mixed activated sludge system having a high B.O.D. removal efficiency.⁴ During the same year Tapleshay reported on the design and efficiency of total oxidation package plants.⁵ He pointed out that the degree of treatment achieved was a function of design. Also in 1958 Symons and McKinney pointed out that not all organic substrate entering the system was totally oxidized but rather that a small residue of non-oxidizable polysaccharide material remained.⁶ Kountz and Forney (1959) using dry skim milk as feed for a total oxidation treatment system found that residual material accumulated in the system equivalent to 20-25 percent by weight of the new activated sludge produced.⁷

During 1959 and 1960 the Ohio Department of Health made extensive field studies of a number of extended aeration package plants being operated in that state and found that properly designed and operated plants were capable of achieving a high degree of treatment.² Joplin (1960) reported on a field study of ten extended aeration package treatment plants in California and stressed the relationship of routine operational and maintenance attention to the degree of treatment achieved.⁸ Kiker (1960) reported a field study of fourteen extended aeration package plants in Florida which also stressed the importance of operation and maintenance.⁹ Porges and Morris (1960) presented a review of the information then available on extended aeration package plants which pointed out both their basic usefulness and limitations.¹⁰

One of the most thorough analysis of process fundamentals was presented by Ludwig *et al* in 1960.¹ This was followed by a somewhat condensed presentation of the material by Stewart and Ludwig in 1962.^{11, 12} Shatto (1960) demonstrated that a package plant effluent free of detectable B.O.D. could be produced by using a diatomite filter as the final treatment step.¹³ In 1961 Howe presented a discussion of package plant operational problems.¹⁴ Ludzack, Schaffer, and Ettinger (1961) demonstrated the importance of temperature and feed as process variables.¹⁵ During 1961 a study of fourteen package plants in

Massachusetts to determine how actual performance and operation correlated with theoretical concepts was reported.¹⁶ This study found that with proper design and operation these plants were capable of producing a satisfactory effluent. Based on the information developed during the study, an operating manual was developed.¹⁷ Baker (1962) following a study of package treatment plants in Florida reported the belief that such units were capable of achieving a better than 95 percent B.O.D. and suspended solids removals.¹⁸

Another thorough analysis of extended aeration package plant fundamentals was presented by McCarty and Brodersen in 1962.¹⁹ Porges and Morris (1962) presented a discussion of the criteria for utilization of extended aeration package plants.²⁰ Stewart, Ludwig, and Kearns (1962) found that extended aeration plants were capable of satisfactory performance under conditions of constant or varying salinity over a relatively wide range.²¹ Washington and Symons reported on the accumulation of volatile solids in activated sludge systems during 1962.²² An extensive review of the mathematics of completely mixed activated sludge systems was presented by McKinney in 1963.²³ Also in 1963, the effect of extended aeration package plant effluent on intermittent watercourses was detailed by Morris *et al.*²⁴

Sludge loading and dissolved oxygen as activated sludge process variables were studied by Orford, Heukelekian, and Isenberg, 1963.²⁵ Pfeffer (1963, 1966) has reviewed extended aeration design criteria.^{26,27} Additional studies and observations on package plants in Florida were reported by Baker in 1964.²⁸ Lawton and Norman (1964) detailed studies on aerobic digestion.²⁹ Monn (1964) reviewed the design and maintenance of extended aeration plants.³⁰ Schulze (1964, 1965) presented a mathematical model for the activated sludge process.^{31,32} Ludzack reported on an extensive bench-scale study of extended aeration in 1965.³³ Rao and Gaudy (1966) demonstrated the importance of sludge concentration as a process variable.³⁴ Smith (1966) reported on homogeneous activated sludge studies.³⁵

From the foregoing it is evident that much knowledge has been gained and much development has taken place in the package plant field during the past twenty years. Further, many fundamental studies have been made which have an impact on this field. In the sections which follow, this information which has been developed will be related to the findings of the present study so that as complete a picture as possible of our present knowledge in this area can be presented.

Coincident with the studies reported above was the commercial development of the extended aeration package plant concept. In 1950 only three such plants were reported while today many thousands are in use. This rapid growth and widespread application of a new concept in waste treatment left many questions unanswered. One of the prime unanswered questions was how to evaluate the performance of extended aeration package plants.

PROJECT HISTORY

In 1956 the Sewerage Committee, Engineering Section, Michigan Public Health Association expressed an interest in packaged treatment plants and a desire to explore on a national scale whether agreement could be reached on how to evaluate the performance of these plants. In 1957 this committee called a meeting of interested public health, sanitary engineering, user, manufacturer, and other groups and agencies to examine this question. The meeting was held at Michigan State University on April 27th of that year. It was the consensus of those attending this meeting that there was a need for units possessing the characteristics generally attributed to packaged plants, that additional information was needed on performance and control, and that some independent testing agency such as the National Sanitation Foundation would provide a valuable service if it would make a study of these plants. This proposal did not go forward because of the lack of financial support.

In 1961 the Great Lakes Upper Mississippi Board of State Sanitary Engineers requested its Sewage Works Standards Committee to find a means of developing performance evaluation criteria for packaged treatment plants. During 1962 the Board on the recommendation of its committee directed the committee chairman to explore whether the National Sanitation Foundation would undertake such a study.

Pursuant to the action of the Great Lakes Upper Mississippi Board, above, and supported strongly by the resolution adopted by the Board recommending this course of action, the Foundation appointed an interim Joint Industry-Public Health Committee which developed through a number of work sessions a proposed methodology for the study and an application seeking a U.S. Public Health Service Demonstration Grant for the financial support of the project. Additional support for this course of action came from the Conference of State Sanitary Engineers and the Association of State and Interstate Water Pollution Control Administrators.

The Foundation application was subsequently approved and given high priority by the Demonstration Grants Committee (now a part of the Federal Water Pollution Control Administration) of the U.S. Public Health Service in 1964. This grant which is known as WPD-74 was given an effective date of January 1, 1965 and provided \$150,075.00 for the first year's work and contemplated at least two additional years of research each with a total budget of \$90,600.00

PROJECT METHODOLOGY AND FACILITIES

January 15, 1965 represented the ending of one era and the beginning of another insofar as this project is concerned for it was on that day that the last meeting of the interim Joint Industry-Public Health Committee was held and it was at that meeting that the Foundation announced the project as an official Foundation study. Immediately following the meeting the Foundation appointed the following committees to serve throughout the project:

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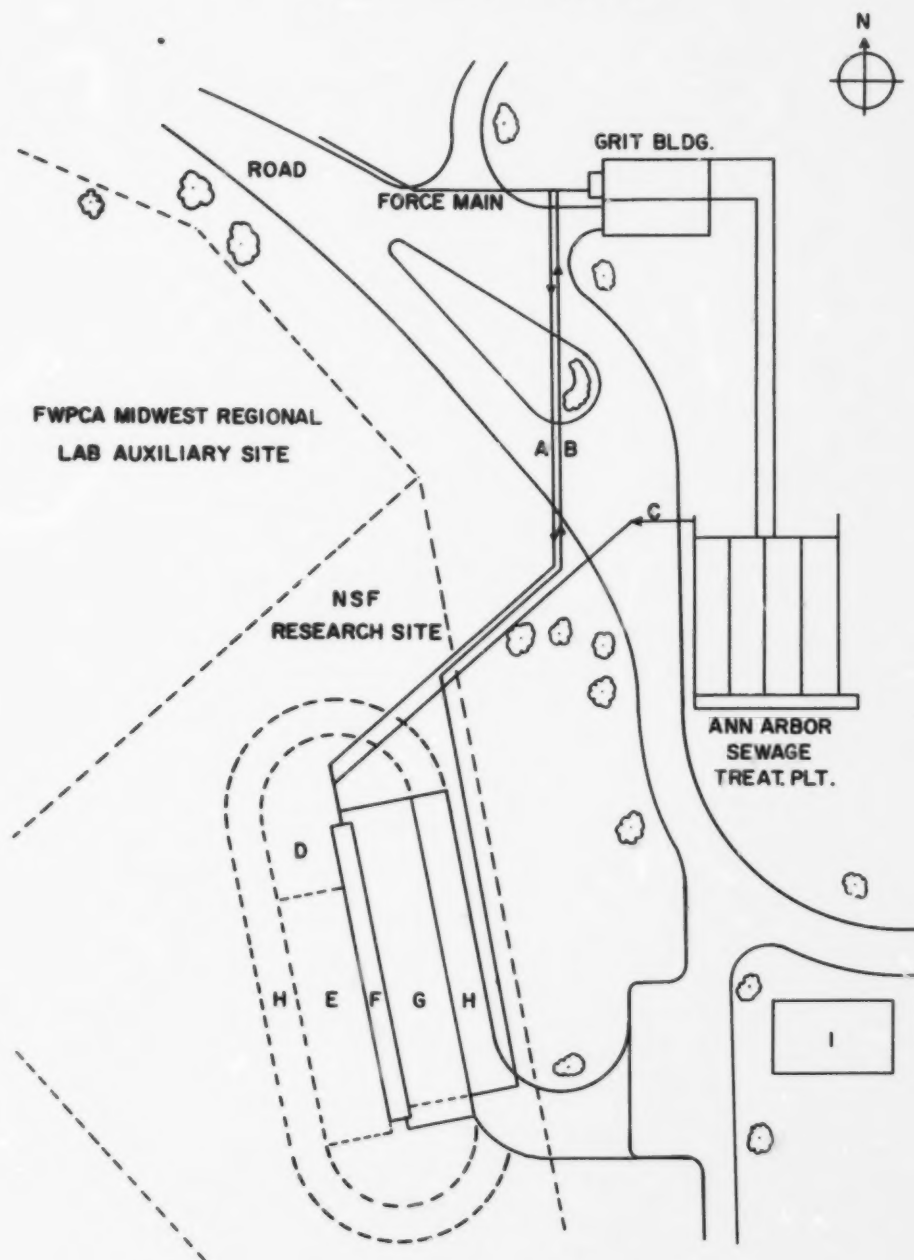
The Technical Committee held a two day meeting in Ann Arbor on March 11 and 12, 1965 at which time detailed plans were presented by the committee's engineering consultant, Mr. George Hubbell, Hubbell, Roth and Clark, for the project's research site facilities. The committee made the following sixteen (16) recommendations to the Policy Committee:

1. The physical facilities to be constructed for this project should be those outlined

by Hubbell, Roth and Clark, see Figures No. 1, 2, 3, & 4.

2. Plants studied should be identified by number only and all data held as confidential under rules to be specified by the Policy Committee.
3. During the first year the project should be limited to extend aeration package plants, in the broadest meaning of the term, unless found possible to study other types without detriment to the extended aeration study.
4. At least nine package plants should be utilized in the initial study and these divided into three groups of three plants each. Each group of plants to be operated under a different hydraulic and organic loading pattern.
5. Plants selected for use in this project should be operated in all respects in accordance with the manufacturers' instructions with the exception of the variations in flow, flow patterns, and organic loadings.
6. Each series of tests should include both Summer and Winter operations.
7. During Winter operations the package plants should be protected by wind breaks and other devices to provide essentially the same protection to the plants as that afforded by below grade installation.
8. Plants should be given necessary operational and maintenance attention with the nature and extent of this attention being reported in detail.
9. Detailed operational records should be kept including observed meter readings and the like as well as the personal observations and comments of the operating staff. Detailed maintenance records should be kept in like manner.
10. Observations should be made and reported on the effect of process interruptions. Such interruptions to be either the natural result of the hydraulic pattern in use at the time or the intentional simulation of power failure and other conditions as time and opportunity permit.
11. Observations should be made on the effect of the following and reported:
 - (a) Optimum aerator solids concentration
 - (b) Need for solids wasting
 - (c) Optimum return sludge rates
 - (d) Effectiveness of aerator mixing

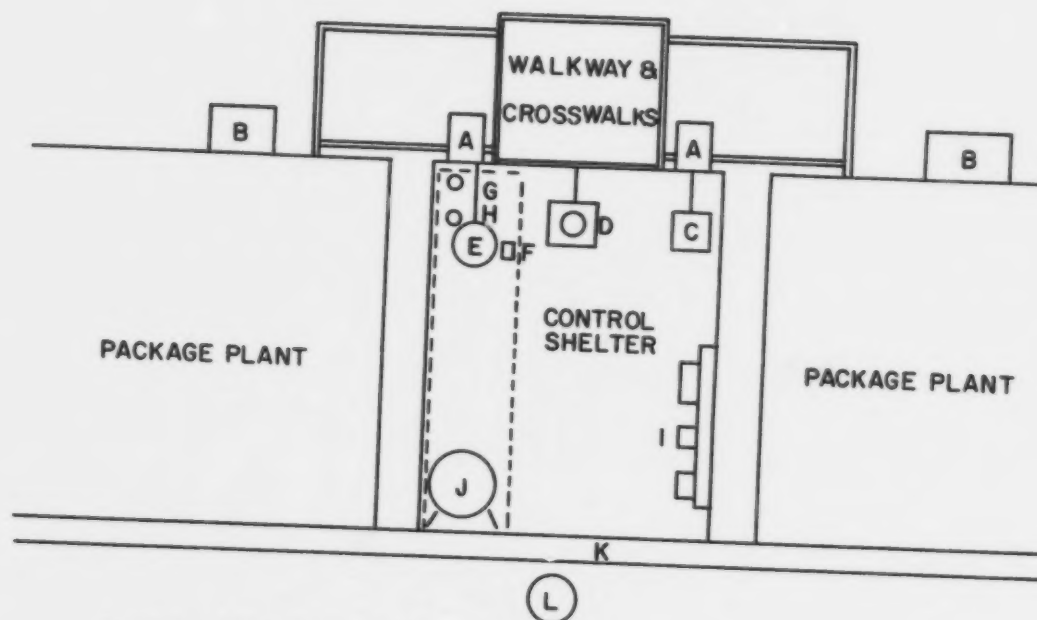
Fig. 1. General Research Site Plan



A - RAW SEWAGE LINE
 B - RETURN LINE
 C - WATER LINE
 D - AREA FOR CONCRETE PLANTS

E - CONCRETE SLAB FOR STEEL PLANTS
 F - CONTROL SHELTER
 G - CONCRETE SLAB FOR STEEL PLANTS
 H - ROAD
 I - ANN ARBOR STP OFFICE & LAB

Fig. 2. Control Shelter and Piping, Typical Section

TYPICAL SECTION

A - FLOW SPLITTING DEVICE
 B - PLANT AIR BLOWER
 C - ELECTRIC DUCT 480 V.
 D - ELECTRIC HEATER
 E - RAW SEWAGE HEADER

F - MAGNETIC FLOW METER
 G - AIR HEADER
 H - WATER HEADER
 I - CONTROL PANEL
 J - RAW SEWAGE PUMP
 K - CONCRETE SLAB
 L - EFFLUENT COLLECTION &
 DRAINS

Fig. 3. Research Site Flow Diagram

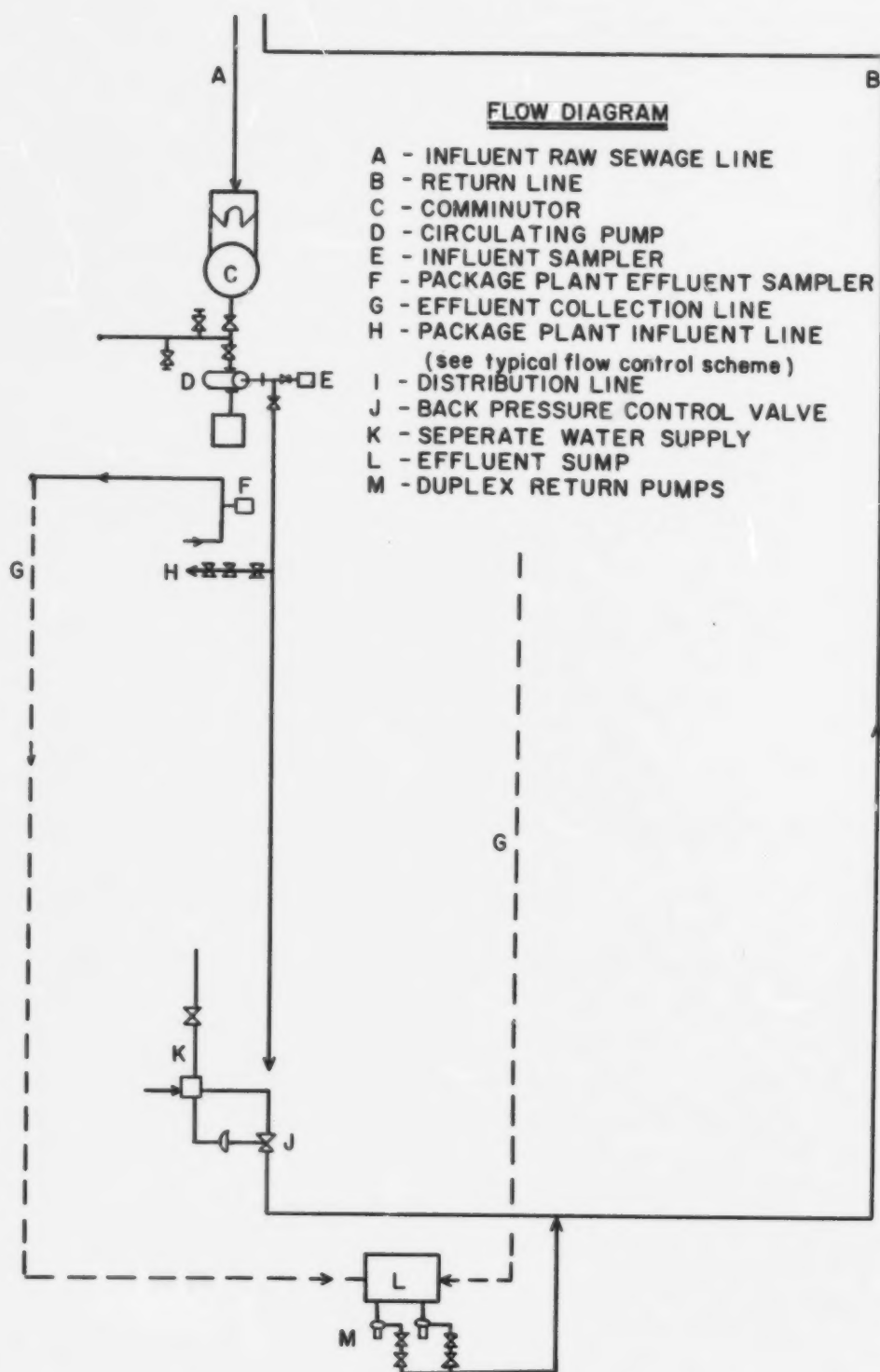
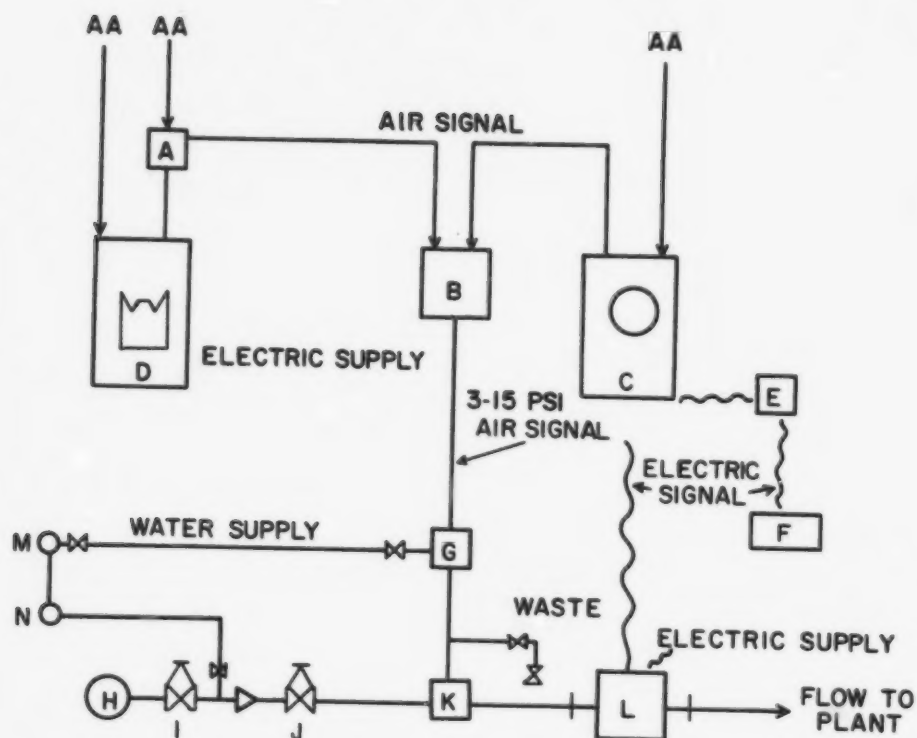


Fig. 4. Typical Flow Control Scheme

TYPICAL FLOW CONTROL SCHEME

- | | |
|--|--------------------------|
| A - 1:1 AIR RELAY | J - THROTTLING VALVE |
| B - CONTROLLER | K - CONTROL VALVE |
| C - FLOW INDICATOR, RECORDER,
TOTALIZER & TRANSMITTER | L - MAGNETIC FLOW METER |
| D - PROGRAM SET POINT TRANS. | M - FILTER |
| E - PULSE COUNTER | N - WATER HEADER |
| F - EFFLUENT SAMPLER | AA - FILTERED AIR SUPPLY |
| G - AIR WATER RELAY | |
| H - RAW SEWAGE HEADER | |
| I - GATE VALVE | |

12. The need for and effectiveness of methods for foam control should be observed and reported.
13. The normal operational reports should include observations on: (a) foam (b) odor (c) scum (d) noise (e) safety (f) color of aerator contents (g) effluent turbidity. These reports should also include a record of labor and supplies required by each unit.
14. Detailed maintenance reports should contain a record of labor, parts, and supplies required by each unit and a report of and down time.
15. Laboratory Analyses:

Standard BOD₅, suspended and volatile suspended solids tests should be run daily on all composite samples. Other tests should be run as frequently as possible. The following tests should be made on the samples as indicated:

A. RAW SEWAGE

- (1) Measurement of flow to each unit
- (2) Temperature
- (3) pH
- (4) B.O.D. (including K rate, carbonaceous and nitrogenous, soluble and total)
- (5) C.O.D.
- (6) Suspended and volatile suspended solids
- (7) Total and volatile total solids
- (8) Organic nitrogen, ammonia nitrogen, nitrite and nitrate
- (9) Phosphates
- (10) A.B.S./L.A.S.

B. PACKAGE PLANT EFFLUENTS

The same as in A. above, with the exception of item (1) and the addition of dissolved oxygen determinations.

C. "TN-PLANT" SAMPLES

- (1) Aeration Tank
 - (a) Dissolved oxygen
 - (b) Suspended and volatile suspended solids
 - (c) Solids settling rate (SVI-SDI)
- (2) Return Sludge
 - (a) Volume (rate of flow)
 - (b) Suspended and volatile suspended solids
- (3) Waste Sludge
 - (a) Volume
 - (b) Suspended and volatile suspended solids

16. One or more studies of the oxygen transfer coefficient of Ann Arbor sewage should be made.

On April 12, 1965 the Policy Committee met in Chicago and considered the Technical Committee recommendations in detail. The recommendations were adopted by the Policy Committee at that meeting without significant change.

Bids were immediately taken on the necessary construction work and construction was begun on April 28, 1965. Much of the material required was on hand by the end of May 1965, site grading was completed, and major construction was in progress, by the low bidder, Midwest Mechanical Contractors, see Figures No. 5 thru 14. Concurrent with the foregoing activities the Foundation had conducted an extensive search of the pertinent literature, studied the characteristics of the Ann Arbor Sewage which would be utilized in the project, see Figures No. 15 thru 19, and secured the agreement of a number of manufacturers to supply packaged sewage treatment plants for use in the project. Further, during construction, the project staff had grown to include, in addition to the Project Director, Mr. Brian L. Goodman, Mr. John G. Havens (Research Site Manager), Mr. Robert S. Greathouse, Sr. (Project Chemist), Mr. Wendell Birdsall (Research Assistant), and Mrs. Adeline Carter (Project Secretary). Mr. Jonn Karr (Research Assistant) joined the staff early in 1966.

The first package plant was delivered by its manufacturer to the research site on June 23, 1965 and fourteen others have since been supplied. The research site occupies two acres of land immediately adjacent to the Ann Arbor Sewage Treatment Plant at 49 S. Dixboro Road, Ann Arbor, see Figure No. 1. This land was provided under a license agreement by the U.S. Public Health Service. The auxiliary site for the U.S.P.H.S. Midwest Regional Laboratory occupies three acres of land adjoining the NSF Research site.

A ten inch tap has been made on the Ann Arbor Sewage Treatment Plant 48 inch inlet force main just ahead of the plant's screening and grit removal facilities. From this point sewage flows through a ten inch line to the research site where it passes through a one-fourth inch slot comminutor. The sewage is then pumped at the rate of 1,000 gallons per minute through a distribution line running the length of the research site. The package treatment plants are located along this distribution line and are fed sewage from it. The rate of flow to each unit is automatically controlled and so programmed as to simulate various

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PACKAGE SEWAGE TREATMENT PLANT RESEARCH SITE CONSTRUCTION



Fig. 5. April 28, 1965, Site Preparation



Fig. 6. May 26, 1965, Control Shelter Sections

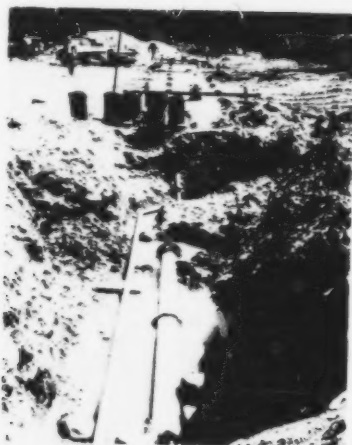


Fig. 7. June 21, 1965, Control Shelter, Underdrains and Piping



Fig. 8. June 23, 1965, First Plant Arrives

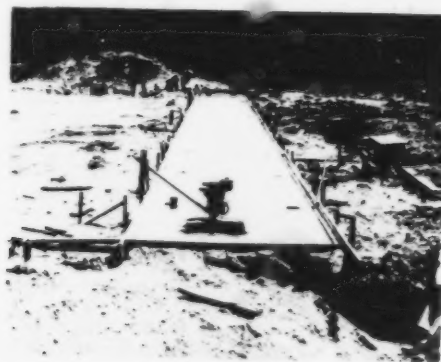


Fig. 9. June 28, 1965, Control Shelter Slab

NATIONAL SANITATION FOUNDATION
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Fig. 10. June 30, 1965, Pouring Slab for Plants.



Fig. 11. July 10, 1965, Installation of Concrete Tank Plants.

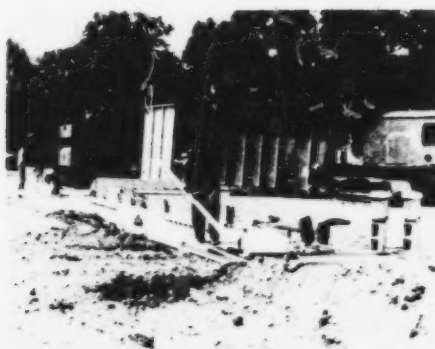


Fig. 12. July 12, 1965, Installation of Steel Tank Plants

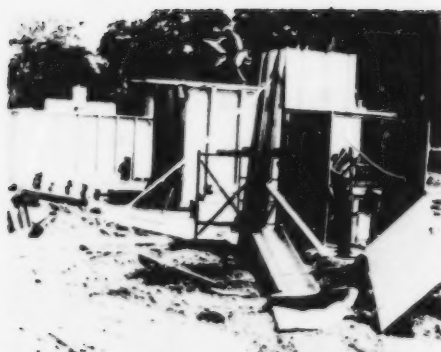


Fig. 13. July 13, 1965, Erection of Control Shelter



Fig. 14. July 15, 1965, Control Shelter Erection & Distribution Header Sections

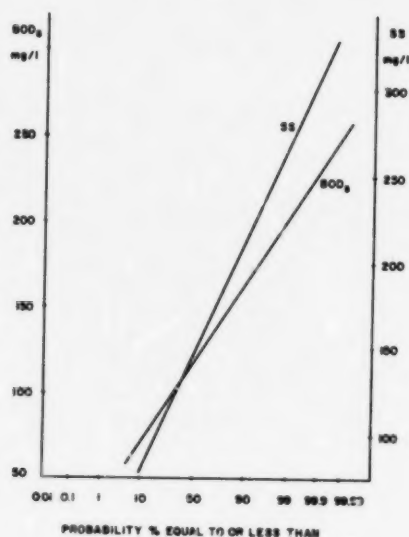


Fig. 15. City of Ann Arbor, Michigan, Raw Waste

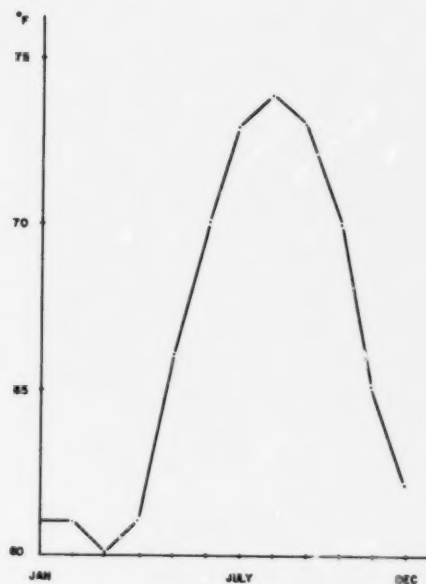


Fig. 16. City of Ann Arbor, Michigan, Raw Waste Temperature.

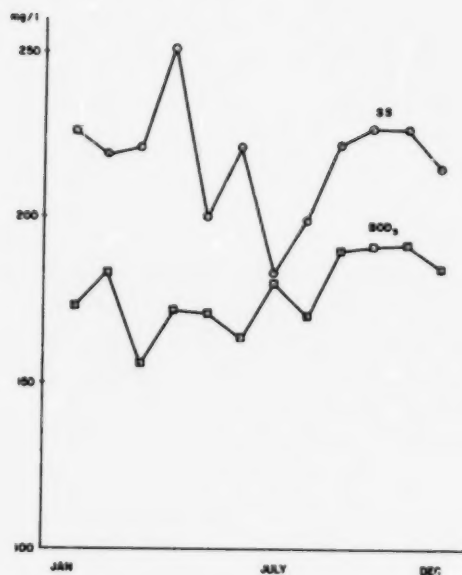


Fig. 17. City of Ann Arbor, Michigan, Monthly Raw Waste Variation Mean Values

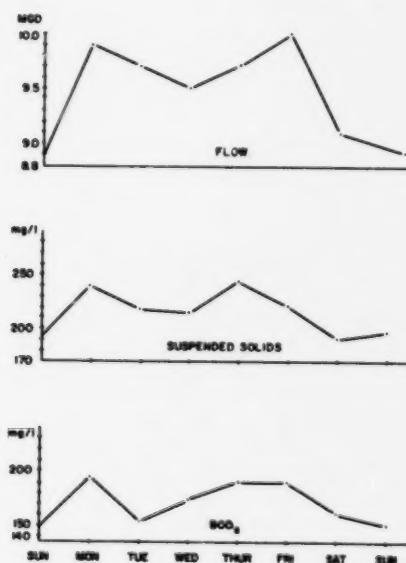


Fig. 18. City of Ann Arbor, Michigan, Raw Waste Daily Variation

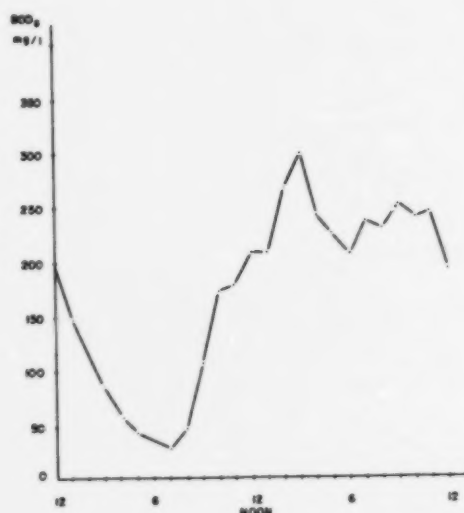


Fig. 19. City of Ann Arbor, Michigan, Hourly BOD₅ Concentration Curve Raw Waste.

typical applications such as subdivisions, schools, and the like. Each flow control unit consisted of a flushing connection, a manual throttling valve, an air to hydraulic operated flow control valve, a magnetic flow meter, a flow indicator, recorder, totalizer with pneumatic transmitter, a flow controller proportioning and reset, to operate by air signal the air water relay to control the valve, together with the necessary flexible pipe connections to the treatment unit(s). In addition, program set point transmitters were used to enable any flow pattern to be set up. Each of these units could be used to control any number of control valves. The cam for the programming transmitters were field cut to provide the desired flow program. Each control unit was capable of controlling the flow for up to four package treatment plants through the use of a flow splitter weir box.

Influent and effluent samples were collected by automatic samplers and composited proportional to flow. Hydraulic conditions were automatically maintained in the distribution system such that the deposition of solids was prevented. Excess sewage was returned to the Ann Arbor Sewage Treatment Plant inlet for treatment. Following sampling, the effluent from the package plants was likewise returned to the Ann Arbor Plant inlet. All controls and samplers were contained in the 140 foot long control shelter which also housed the laboratory and field facilities, see Figures No. 1, 2, 3, & 4.

Ten steel package plants were located on the East side of the control shelter and set on a continuous 30 foot wide concrete pad. Two concrete package plants were installed on the West side of the control shelter below grade. Two additional steel package plants were located on a 30 foot wide concrete pad located along the West side of the control shelter. The control shelter was 12 feet high with a walkway along the top. Crosswalks from this gave access to the top of these package plants which were installed above grade.

In all, fourteen package sewage treatment plants were loaned to the Foundation for use in this phase of the research project by their respective manufacturers. Additional plants for use in subsequent phases of this study have also been provided.

Beginning with the startup of the first plant on September 14, 1965, a large number of different package treatment plants were operated simultaneously at the research site under a variety of loading levels and patterns as well as the various conditions of weather. The information and experience thus gained formed the core data. This core data was extended through the collection of field data. This activity has been going forward for the past year and a half through the cooperation of many State, county, and local health departments, together with the cooperation of the various manufacturers of these units. This methodology insured that the final criteria were applicable to the widest possible range of plant design, loading, and weather conditions.

It was the objective of this research project to develop criteria for the performance evaluation of package sewage treatment plants. It is important to note that the objective of this study was not to develop design criteria. The performance evaluation criteria are such that the evaluations can be made completely independent of design considerations.

So as to conserve valuable time plants were started and the laboratory was put into operation while major construction was still in progress.

During 1965 it became obvious that in order to carry out the intent of the Technical Committee's recommendations it would be necessary to add to the facilities constructed in 1965. Accordingly, a supplemental demonstration grant application prepared by the Executive Committee and the Foundation Project Staff was submitted to the Grants Committee, Federal Water Pollution Control Administration. This request for an additional \$37,122.00 was approved by the Demonstration Grants Committee to be effective January 1, 1966.

This supplemental grant provided for the construction of additional concrete pad area along the West side of the control building, the acquisition of additional control system components, and necessary equipment and supplies.

Among the questions about extended aeration package treatment plants which this research project has attempted to answer are:

1. What is the effect of load level on performance and performance evaluation?
2. What is the effect of organic and hydraulic loading pattern on performance and performance evaluation?
3. What is the effect of climatic conditions on performance and performance evaluation?
4. What is the effect of design considerations on performance and performance evaluation?
5. Are performance evaluation criteria which are valid for one plant size in a model series applicable to other sizes of the same series?
6. What is the effect of the type of organic loading on performance and performance evaluation?
7. If one desired to evaluate the performance of a plant, what analytical procedures would he use?
8. In the performance evaluation of a plant, what period of time is required for the evaluation?
9. What are the effects of operating and process variables on performance and performance evaluation?
10. What are the interrelationships, if any, that exist between the above and other factors?

The present project represents a more than one half million dollar joint effort on the part of the water pollution control profession, the federal government, and the manufacturers of package plants to answer these and similar questions in seeking a means of plant performance evaluation.

In order to eliminate bias from the deliberations of the various project committees the identities of the manufacturers of the various package plants used in the research were not disclosed to the committee members and all data was presented to them identified only by code numbers. The project data is presented here in the same manner.

During the first one and a half years of this project which is covered by this report, some several thousand persons have visited the Research Site. The record number of visitors for one day was over two hundred. Among these visitors have been representatives of most state water pollution control and public health agencies, many federal departments and agencies, professional societies, universities, and the like.

EXTENDED AERATION PLANTS

Before proceeding to a more detailed discussion of process fundamentals it would perhaps be useful to consider for a moment the basic features of extended aeration plants.

Extended aeration package sewage treatment plants consist of two main parts, the aeration compartment and the final settling or clarification compartment. Raw sewage flows directly into the aeration compartment without having first been subjected to primary sedimentation. A trash trap, bar screen, and/or comminutor, however, may sometimes be used ahead of the aeration compartment. Within the aerator the raw sewage is mixed with the return sludge to form the mixed liquor which is aerated for from 18 to 30 (commonly 24) hours. At the end of the aeration period, the mixed liquor flows into the sedimentation or clarification compartment where the suspended solids (MLSS) and liquid are separated by gravity. The separated solids are returned to the aeration compartment as the return sludge (RSSS) while the liquid flows out of the plant as the plant effluent. This effluent may or may not be chlorinated prior to final disposal in a river or lake. Sometimes a sand filter or lagoon is used following the plant to further purify the plant effluent prior to final disposal. Foam control

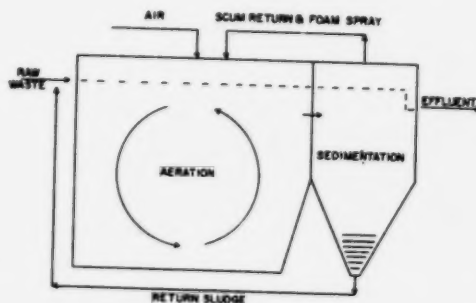


Fig. 20. Simple Extended Aeration Plant

TYPICAL PACKAGE SEWAGE TREATMENT PLANTS

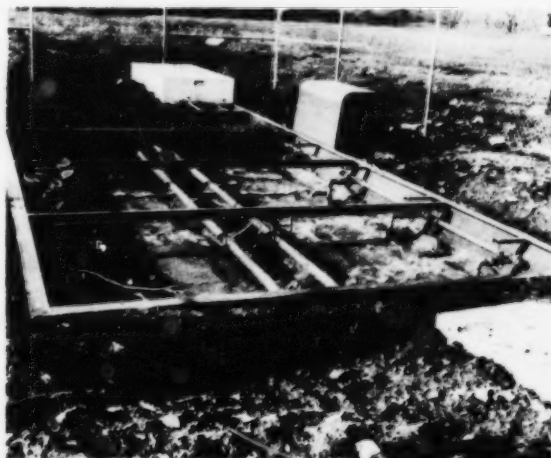


Fig. 21.

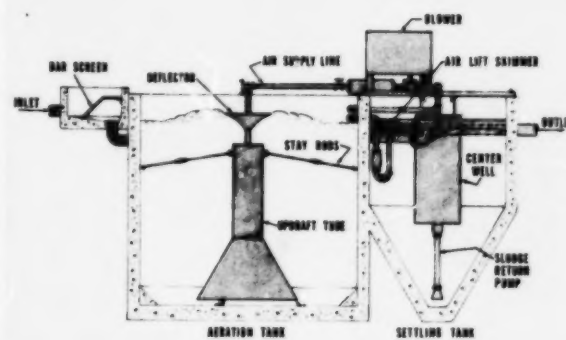


Fig. 22.

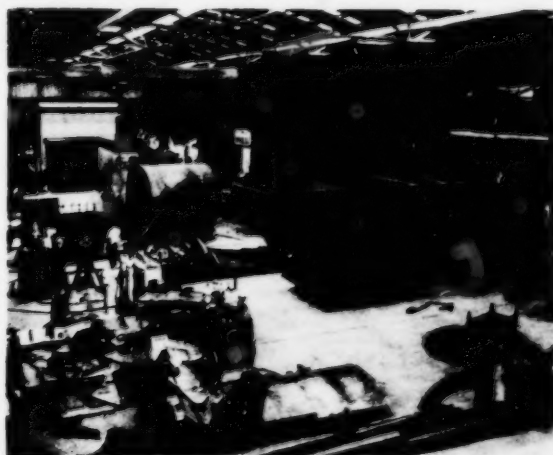


Fig. 23

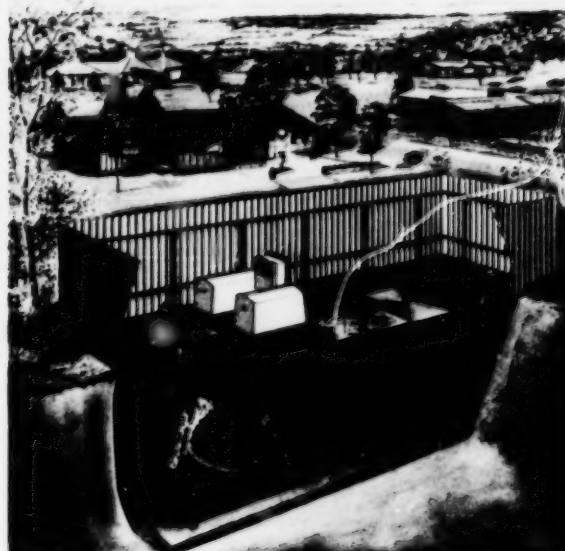


Fig. 24

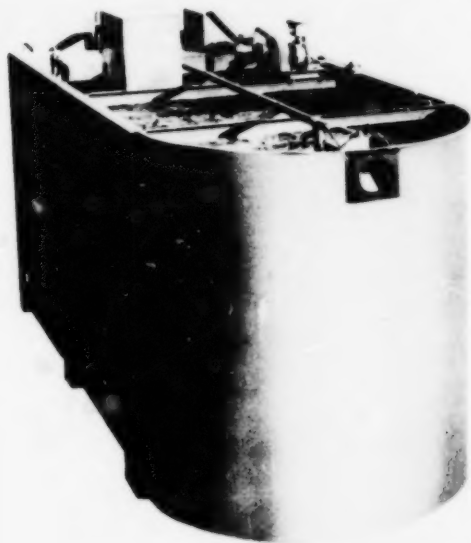


Fig. 25



Fig. 26

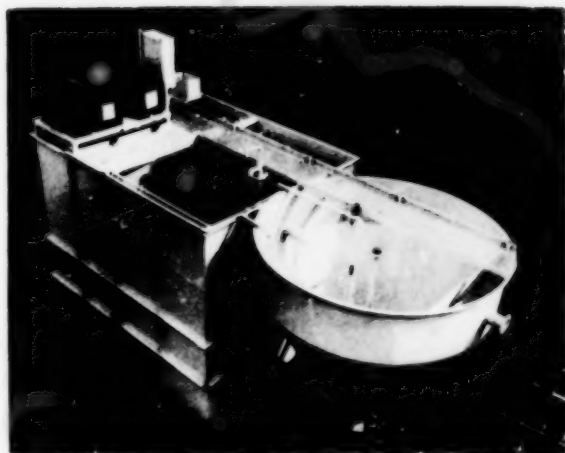


Fig. 27

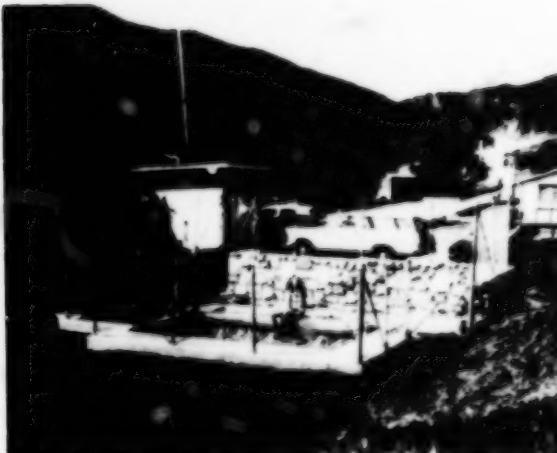


Fig. 28

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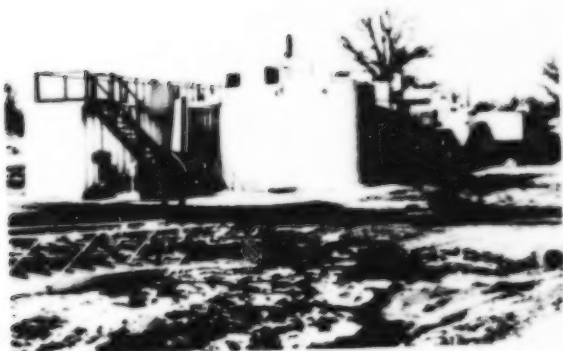


Fig. 29. January, 1966, Overall View



Fig. 30. Control Shelter Laboratory Section



Fig. 32. Access to Plants from Top of Control Shelter

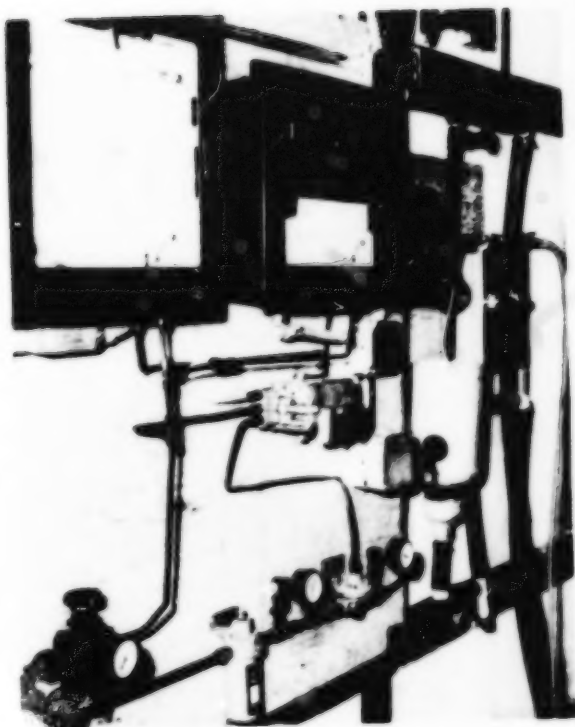


Fig. 31. Flow Control Panel



Fig. 33. Walkway on Top of Control Shelter

sprays and skimmers to remove floating material from the surface of the clarification compartment are also commonly included. Aeration of the mixed liquor is by diffused aeration, mechanical aeration, and variations and combinations of these methods. Settled sludge and scum are returned to the aeration compartment usually by the use of air lifts, however, gravity and hydraulic methods are also employed. Excess sludge is withdrawn from the unit from time to time as needed. This waste sludge is frequently disposed of through septic tank cleaning companies or on sand beds adjacent to the

plant. Separate aerobic sludge digestion tanks are often used prior to final disposal of the sludge to further reduce the volume of sludge to be disposed of. Figure 20 presents the main features of a typical, simple, extended aeration plant. Various types of extended aeration package sewage treatment plants are pictured in Figures 21 thru 28.

"Wherever in this section the words 'aeration compartment' or 'clarification compartment' are used it shall not be construed as restricting such units to single compartments."

II. STUDIES AND FINDINGS

GENERAL

During the Fall and Winter of 1965-66 ten extended aeration package sewage treatment plants were operated at the National Sanitation Foundation's Research Site in Ann Arbor. These plants were operated and maintained in accordance with the recommendations of their respective manufacturers at the design loading for each plant applied steady state with respect to flow. This resulted in organic loadings at, or just below, design. The design daily hydraulic capacities of these plants, based on a twenty-four hour aeration period ranged from a low of 5,000 gpd to a high of 16,000 gpd with intermediate capacities of 7,500, 9,000, 10,000 and 12,000 gpd. Two of these plants were constructed of concrete and the remainder of steel. The concrete plants were installed essentially below grade with the steel tank plants being installed on a concrete pad above grade. Pursuant to the instructions of the Technical Committee, the above grade plants were given winter protection.

The plants were operated by the Research Site staff who made extensive reports on the operating and maintenance time and materials required for each plant. In general, these plants were operated continuously from September 1965 until March 1966, when all but two of the plants were drained and cleaned. During this period 1,830 plant days of operating time was logged.

For the Spring and Summer studies twelve extended aeration package plants were operated at the Research Site beginning in April 1966 and ending in August 1966 for a total operating time of 1,524 plant days. The plants utilized in this portion of the studies were the same as were used in the Fall and Winter studies with the addition of two steel tank plants. The range of plant sizes in the Spring and Summer studies were the same as were noted previously for the Fall and Winter studies. All of the plants used in both sets of studies employed diffused aeration with the exception of one plant in the Spring and Summer studies which employed mechanical aera-

tion. Additional views of various portions of the Research Site are shown in Figures 29 thru 33.

During the Spring and Summer studies a number of different flow patterns were employed. The plants were operated in pairs with the influent flow to the various pairs being programmed as follows:

PAIR	FLOW PATTERN
A	Steady State - Maximum Hydraulic Design
B	Steady State - One Half Hydraulic Design
C	Subdivision - Maximum Hydraulic Design
D	Subdivision - One Half Hydraulic Design
E	School - Maximum Hydraulic Design
F	School - One half Hydraulic Design

These patterns are illustrated in Figures 34, 35, and 36.

The performance of the plants during the various phases of these studies is summarized in Tables I through I-C.

All the plants selected for use in these studies were standard models currently being offered for sale by their respective manufacturers as attested to by catalogs, brochures, and drawings filed with the Foundation prior to acceptance of the plants.

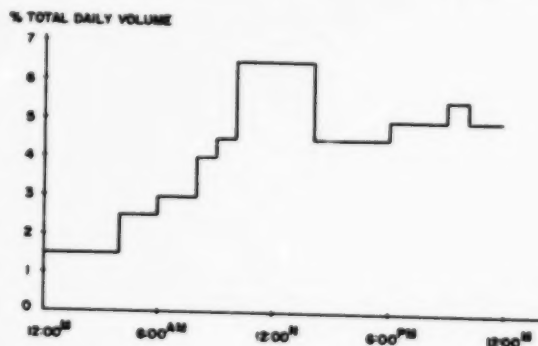


Fig. 34. Subdivision Flow Patterns

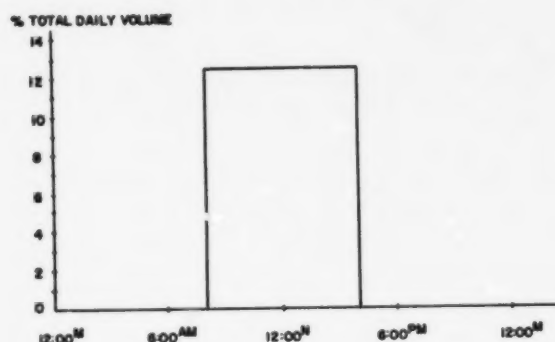


Fig. 35. School Flow Pattern

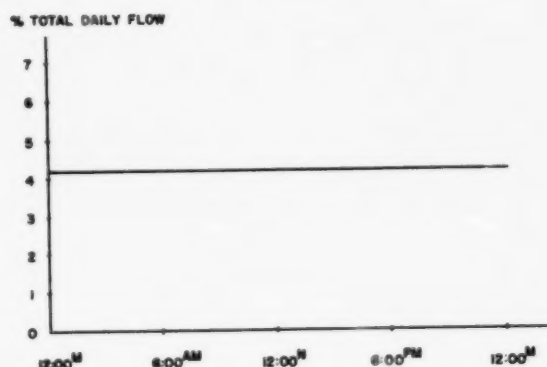


Fig. 36. Steady State Flow Pattern

All analytical methods employed during these studies, except as specifically noted, were those set forth in the latest edition of Standard Methods for the Examination of Water and Wastewater available at the time.^{36,37}

STARTUP AND SOLIDS ACCUMULATION

The startup period for extended aeration package plants is defined as the time between the placing of the plant in service and its attainment of the required level of treatment of the applied waste. Since, as it will be shown, treatment efficiency is, among other things, a function of the active solids mass present in the system it follows that the rate at which such solids accumulate during startup is an important criterion of plant performance.

Solids will accumulate in an extended aeration system so long as the system is operating at less than its equilibrium value or separate sludge wasting is employed to maintain the system at a solids level less than its equilibrium value. Other-

wise, once the system reaches equilibrium, solids will be wasted from the system as they are formed.

The accumulation of solids can be expressed as:

$$A = [(a F - b M_d) + S_i] - x M \dots \dots \dots (1)$$

Where: A = Accumulation of solids
 a = The fraction of F synthesized per unit time
 F = Foodstuff entering the system
 b = The fraction of M oxidized per unit time
 M_d = The mass of degradable solids in the system
 S_i = The inert solids entering the system
 x = Some fraction of M leaving the system in unit time
 M = The mass of solids in the system

This can be illustrated by using the data from plant F-1 during its startup in the Spring and Summer studies:

Where: a = 0.65
 F = 5 lb. BOD /day
 b = 0.18
 M_d = 12 lbs. (as MLVSS)
 S_i = 2.5 lbs./day
 xM = 1.25 lbs./day (as effluent suspended solids)

$$A = [0.65 (5) - 0.18 (12)] + 2.5 - 1.25 = 2.2 \text{ lbs./day (calculated)}$$

$$A = 2.08 \text{ lbs./day (observed, based on observed MLSS increase of 50 mg/1/day)}$$

As the food to microorganism ratio decreases due to the increase of the active sludge mass (some fraction of MLSS) and the fixed influent BOD₅, the net sludge accumulation rate (a F - b M_d) will decrease and will approach but not reach zero, see Figure 37. This has been thoroughly demonstrated by Washington and Symons.²² The oxidation of 1 lb. of BOD results in an inert residue of 0.12 lb. of solids, see Figure 38.

Based on the foregoing, it is clear that the rate at which solids will accumulate in an extended aeration package plant beginning with the placing of the plant in service is dependent on:

1. The rate at which foodstuff enters the plant, therefore, longer startup periods are to be expected in the case of under loaded plants than those which receive their design load from the onset.

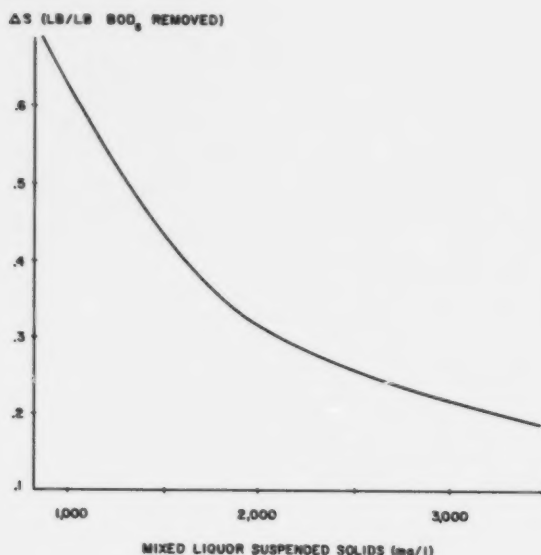


Fig. 37. Solids Accumulation

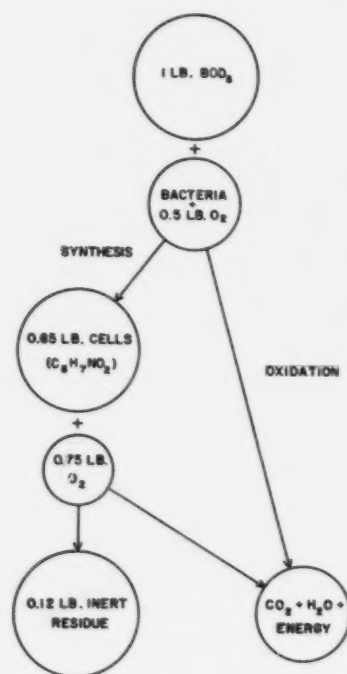


Fig. 38. Mature Extended Aeration Process

3. The rate at which inert solids enter the system.

4. The rate at which solids are being oxidized in the system.

In order to determine the effect of loading on solids buildup one half of the plants in the Spring and Summer studies were started at design load and one half at half design load. The results are given in Table II. Analysis of this data reveals that for the loading levels, patterns, and conditions studied the plants would achieve a mixed liquor solids concentration of 2,500 mg/l in from 36 to 49 days with the highest loadings resulting in the lowest startup times.

TABLE II

Solids Buildup Rate
Spring - Summer Studies

Loading Pattern	Solids Buildup Rate mg/l/day
1. One Half Design Load, Steady State	55
2. Full Design Load, Steady State	61
3. One Half Design Load, Subdivision	51
4. Full Design Load, Subdivision	63
5. One Half Design Load, School	54
6. Full Design Load, School	70

It is recognized that the achievement of mixed liquor suspended solids concentrations sufficient to yield consistently high treatment efficiency in less than 36 to 49 days may be desirable in some cases. In such cases seeding of the treatment unit with activated sludge from a mature unit treating a similar waste is recommended. A second possible method of achieving a high treatment efficiency within a relatively short time was investigated during these studies. This method involved allowing raw sewage to flow through the treatment unit without aeration or sludge return for a period of one week during which time the package plant served in effect as a primary treatment device. At the end of a week the plant is placed into full operation. The use of this method at one point during the studies resulted in a mixed liquor suspended solids concentration of 980 mg/l at the beginning of the full startup period and the achievement of 90% or better BOD₅ removals by the end of the first week of full operation. During the one week period of primary

2. The rate at which solids are lost from the plant, therefore, plants with poorly designed clarifiers or which are overloaded hydraulically will have long startup periods.

treatment BOD₅ removals were 60% or better. This method has been employed by at least one manufacturer of package plants with equal success and other sources report significantly reduced startup times through the use of digested sludges as seed material.

During the Fall-Winter studies the ten plants had an average solids buildup rate of 42 mg/1/day with a range of from 36 to 51 mg/1/day. In this connection it should be noted that the mean sewage strength was significantly lower in the Fall-Winter studies than in the Spring-Summer studies and it is believed that the lower buildup rate is consistent with the characteristics of the sewage employed as feed.

BOD REMOVAL

For package sewage treatment plants of the extended aeration type, the BOD removal from the applied waste will depend on the mixed liquor suspended solids (MLSS) concentration and the time the organisms contained in the mixed liquor suspended solids are in contact with the waste, assuming that the concentration of oxygen in the aerator is not a limiting factor. It is further assumed here that the pH and temperature of the aerator contents are sufficiently near optimum values so as not to seriously impair biological activity and that significant amounts of toxic substances are not present. It will be shown later, however, that temperature is not as significant a factor here as might otherwise be expected.

For a particular waste a relationship of MLSS (S_a) times time (T) versus BOD removal can be established which in general yields a curve similar to that in Figure 39. This relationship is further illustrated by Figure 40.

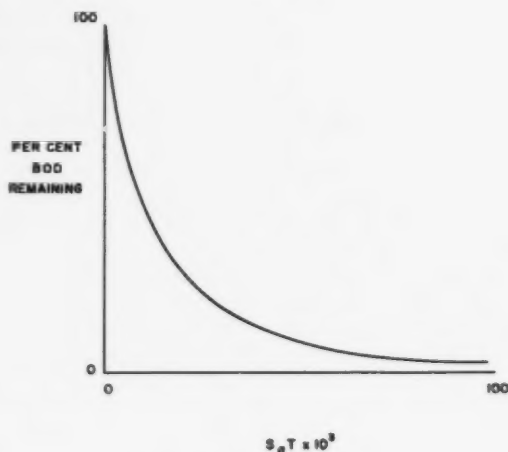
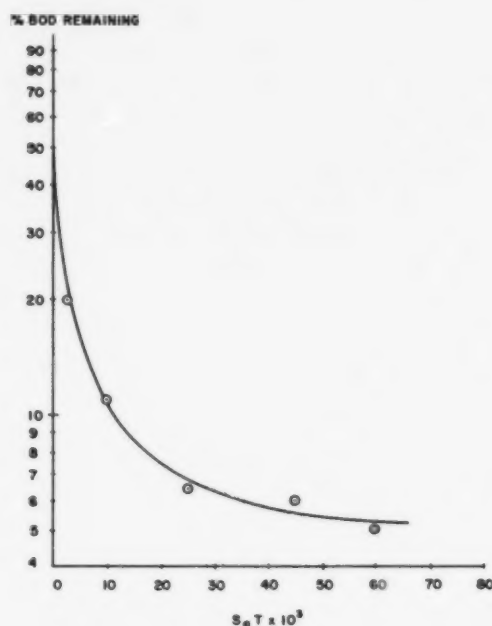


Fig. 39. BOD Removal



* BASED ON MEAN INFLUENT & EFFLUENT BOD₅ - PLANT A-1

Fig. 40. Mean BOD₅ Removal

Conventional activated sludge systems utilizing 2,000 mg/1 MLSS and 6-8 hours aeration yield $S_a T$ values of from 12-16 $\times 10^3$ which result in BOD removals of 90% or greater. The typical extended aeration package plant operates at MLSS values near 5,000 mg/1 and mean aerator detention times of 18-30 hours thus yielding $S_a T$ values of from 90 to 150 $\times 10^3$. MLSS values of up to 10,000 mg/1 are not altogether uncommon in the field. Therefore, for extended aeration plants it is not surprising that BOD removals of greater than 90% are not only common but indeed are to be expected. Substrate BOD is, for all practical purposes, nearly entirely removed by the system.

Since nearly all the BOD entering the system is removed, the effluent BOD will be due almost entirely to the endogenous respiration of the organisms contained in the effluent suspended solids and the effluent substrate concentration, which approaches zero, can be neglected in routine computations. Many researchers, including Ludwig *et al*¹, McCarty and Broderick¹⁹, and McKinney²³ have pointed this out. Therefore, effluent BOD₅ values can be computed as follows:

$$\text{Effluent BOD}_5 = S + C E_s t \dots\dots\dots (2)$$

$$S = \frac{F}{1 + K_{\text{BOD}} t} \dots\dots\dots (3)$$

Where: S = Organic (substrate) concentration, mg/l

C = Solids Degradation Rate (24%/day for mature systems of 20° C, 12%/day at 10° C)

Es = Effluent degradable solids (some fraction of effluent volatile suspended solids), mg/l

t = Time (days)

K_{BOD} = mg/l BOD removed per mg/l BOD remaining per day (180/day at 10° C, 360/day at 20° C)

F = Influent BOD₅, mg/l

The oxygen uptake or respiration rate of the mixed liquor suspended solids can be easily measured, Eckenfelder and O'Connor³⁸, with a value of approximately 5 mg O₂ / gram MLSS / hour being a common one encountered during these studies, see Table III. The effluent suspended solids were shown to exhibit the same oxygen uptake rate as the MLSS from the same plant during these studies which is not surprising since the effluent suspended solids represent some fraction of the MLSS and, as can be seen from the tables, both contain essentially the same fraction of volatile matter. Therefore, knowing the respiration rate of the MLSS will permit the calculation of the effluent BOD₅ with some accuracy. If the specific oxygen uptake rate for

$$\text{Effluent BOD}_5 = \frac{\text{Eff. SS} \times \text{O}_2 \text{ uptake rate (mg/g/hr)} \times 24 \text{ hr/day} \times 5 \text{ days}}{1,000 \text{ mg/g}}$$

$$\begin{aligned} \text{Effluent BOD}_5 &= \frac{\text{Eff. SS} \times 5 \times 24 \times 5}{1,000} \\ &= \text{Eff. SS} \times 0.6 \dots\dots\dots (4) \end{aligned}$$

the MLSS has been determined and is used in the computation, the observed BOD₅ value can be closely approximated.

EXAMPLE

Data Source: Subdivision Pattern - Full Design Loading

Mean Influent BOD₅: 198 mg/l

Mean Effluent BOD₅: 20 mg/l

Mean Effluent SS : 36 mg/l

O₂ Uptake Rate : 4.6 mg/g/hr

$$\text{Effluent BOD}_5 = \frac{36 \times 4.6 \times 24 \times 5}{1,000} = 19.87 \text{ mg/l}$$

$$\text{Effluent BOD}_5 = 19.87 + S$$

$$S = \frac{198}{1 + 360 (1)} = 0.55 \text{ mg/l}$$

$$\text{Effluent BOD}_5 = 0.55 + 19.87 = 20.42 \text{ mg/l}$$

TABLE III

Mean Mixed Liquor Oxygen Uptake Rates
Spring - Summer Studies

Loading Pattern	Oxygen Uptake Rate mg/g/hour	
	Aerator Influent	Aerator Effluent
1. One Half Design Load, Steady State	5.3	3.9
2. Full Design Load, Steady State	5.6	4.6
3. One Half Design Load, Subdivision	5.0	2.6
4. Full Design Load, Subdivision	5.5	4.6
5. One Half Design Load, School	6.9	3.5
6. Full Design Load, School	7.7	4.8

It is, therefore, clear that the degradable influent organic load is almost completely removed by the extended aeration process and that the effluent BOD₅ is due almost entirely to the solids present. This suggests that if S_a T is great enough and the effluent suspended solids are removed by some additional treatment step then the overall process BOD₅ removal efficiency would be very nearly 100 percent. Shatto¹³, as noted previously, found that when the effluent from an extended aeration package sewage treatment plant was passed through a diatomite filter the overall process BOD₅ removal efficiency was 100 percent for all practical purposes by virtue of the fact that no detectable BOD₅ remained in the effluent.

BOD₅ removals of 90% or better, based on mean influent and effluent values, were observed for all plants in this study for all levels and patterns of loading employed except for the pair of plants which received their total design daily hydraulic load in an eight hour period (school pattern). This sustained high hydraulic loading resulted in the washout of sufficient solids to significantly raise the effluent BOD₅ concentration with the result that the mean BOD₅ removal fell to 82 percent. This result, however, was to be expected as will be shown later in the section on clarification.

A mixed liquor suspended solids concentration of 2,500 mg/l has been taken as evidence of process maturity based on the performance of the plants in this study during the time they were being operated at maximum design loading applied steady state with respect to flow. Figure 41 shows that beginning at approximately this point sustained BOD₅ removals of 90 percent or better were achieved.

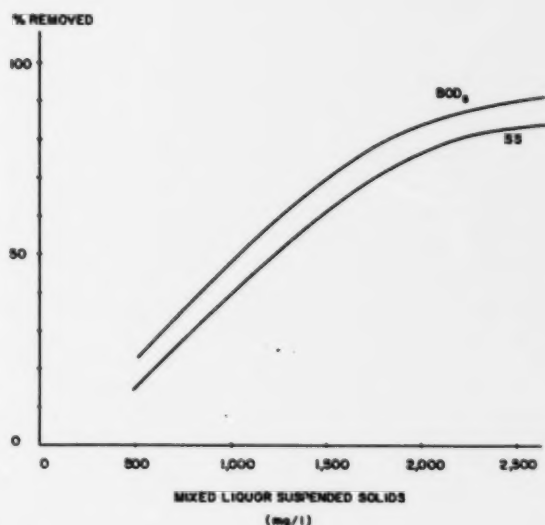
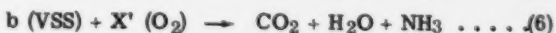


Fig. 41. Mean BOD₅ & SS Removal, Ten Extended Aeration Plants

OXYGEN REQUIREMENTS

Oxygen will be required for both synthesis and oxidation:



Where: X = wt. of oxygen required per wt. of BOD₅ removed

X = wt. of oxygen required per wt. of VSS destroyed

Based on the formula $\text{C}_5\text{H}_7\text{NO}_2$ for the biological VSS produced, X' can be evaluated as equal to 1.415.

Recently Schultze^{31,32} working with a pure culture and glucose found that 37 percent of the glucose assimilated was oxidized and 63 percent was synthesized. He also found that approximately 0.77 gram of oxygen was required per gram of cellular material synthesized. This represents a value of $X = 0.485$ and $a = 0.63$.

In the following discussion, the values used will be:

$$X = 0.5$$

$$a = 0.65 (0.53 + 0.12)$$

$$b = 0.18$$

$$X' = 1.42$$

The maximum oxygen required in terms of pounds of oxygen per pound of BOD₅ removed will be:

$$\text{O}_2 / \text{BOD}_5 = 0.5 + 1.42 (0.53) = 1.2526 \dots (7)$$

At an oxygen concentration of 0.0176 lbs. oxygen per ft³ free air and a transfer rate of 5% or 0.05, the free air requirement per pound of BOD₅ removed per day will be:

$$\text{ft}^3 \text{ air} / \text{lb BOD}_5 = \frac{1}{0.0176 \times 0.05} \times 1.25 = 1416 \dots (8)$$

But, alpha (the ratio of oxygen transferred in a waste to oxygen transferred in water) is approximately 0.95 for domestic waste, therefore:

$$\text{ft}^3 \text{ air} / \text{lb BOD}_5 = 1416 \times \frac{1}{0.95} = 1490 \dots (9)$$

It must, however, be remembered that BOD₅ will not be entering the plant uniformly. From a practical standpoint it is not correct to size blower capacity as:

$$\begin{aligned} \text{Air Requirement} &= \frac{1490 \text{ ft}^3/\text{lb BOD}}{1440 \text{ min/day}} \\ &= 1.035 \text{ cfm} / \text{lb BOD} \dots (10) \end{aligned}$$

In the case of a school for instance all the daily load might enter the plant in eight (8) hours and this fact would have to be taken into account if satisfactory dissolved oxygen levels are to be maintained throughout the day.

If nitrification is to be provided for additional air will have to be supplied.

All of the plants used in this study proved capable of maintaining a residual dissolved oxygen concentration in their aeration compartments of 2.0 mg/l or better, except immediately in the area of raw waste introduction, at all times and under all conditions of loading. All but one of the plants in the study utilized diffused aeration with the one exception being a plant employing mechanical aeration. Judged on the basis of performance, the method of aeration is unimportant so long as it produces the required mixing effect and oxygen transfer in the aeration compartment. While there may very well be economic and other considerations, the type of diffusers employed is

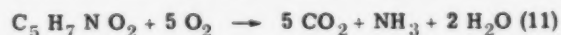
unimportant so long as the required mixing and transfer is achieved.

During the present studies several types of testing were carried out on the plants being used to determine if solids deposition was occurring in their aeration compartments. All of these tests were negative and it was concluded that within normal mixed liquor suspended solids ranges, BOD₅ loadings of from 50-100% of design, and sufficient air being introduced into the aeration compartment to maintain a residual dissolved oxygen concentration of from 1-2 mg/l this amount of air was sufficient to provide adequate mixing of the compartment's contents regardless of the means of aeration utilized in these studies.

In some of the plants in these studies air was introduced only at or near the center of the aeration compartment, in some plants at the effluent end, in others at the influent end, and in still others air was introduced along one or both sides of the aeration compartment. In the various studies made, it appeared that the point of air introduction was important only as it related to the overall geometry of the particular aeration compartment in question.

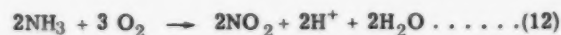
NITRIFICATION

When sufficient oxygen is supplied, extended aeration package sewage treatment plants are capable of a high degree of nitrification. Ammonia nitrogen is a constituent of the waste fed these treatment plants. Ammonia nitrogen is released into solution within such treatment plants as the result of the auto oxidation of cellular material:



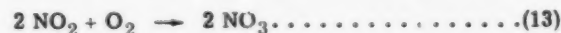
1 lb. cell material + 1.42 lb. oxygen $\rightarrow$ 0.15 lb. NH₃

Ammonia nitrogen can be subsequently oxidized to nitrite:



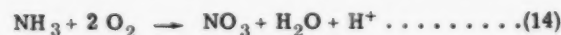
1 lb. ammonia + 2.8 lb. oxygen $\rightarrow$ 2.7 lb. nitrite

Nitrite can be further oxidized to nitrate:



1 lb. nitrite + 0.35 lb. oxygen $\rightarrow$ 1.35 lb. nitrate

Equations 12 and 13 can be combined:



0.15 lb. ammonia + 0.56 lb. oxygen $\rightarrow$ 0.55 lb. nitrate

Thus for the oxidation of one pound of degradable cell material a total of 1.98 pounds of oxygen are required if the oxidation is to be carried completely through to nitrate.

During one portion of the present studies no particular attempt was made to control aerator dissolved oxygen levels except to maintain them above 1.0 mg/l with the result that levels of 5.0 mg/l or greater became common. At these dissolved oxygen levels a high degree of nitrification was experienced with subsequent denitrification in the settling portions of the plant and nitrogen flotation of sludge solids resulting in an impairment of effluent quality due to the presence of increased amounts of solids and related BOD₅. All but two of the ten plants in operation at the time were originally equipped with a baffle just ahead of the effluent weir and in the case of those plants so equipped the floated solids were largely trapped by the weir and held in the plant, however, since they were trapped at the surface of the settling compartment they were not being returned to the process and so the food to microorganism ratio in the aerator rapidly changed and the process began to fail due to the imbalance. An attempt to combat this problem by the continuous operation of the skimming mechanisms with which all plants were equipped resulted in such high up-flow rates in the settling compartment that in many cases this upflow potential exceeded the settling potential of the sludge and resulted in additional losses of solids. When the skimming mechanisms were not operated continuously the floated solids became concentrated at the surface of the settling compartments and in several severe cases nearly all the sludge in the plant was thus removed from the process. It was found that one control method was to reduce the intensity of aeration and to thus carry a lower aerator dissolved oxygen level. In the case of those plants having a baffle ahead of the effluent weir, symptomatic relief could be achieved by operating the skimmers once or twice a day while hoseing down the surface of the settling compartment. The problem of denitrification can be illustrated by the following equation:



The reason for denitrification is the utilization of nitrate by the respiring organisms as a secondary source of oxygen in the absence of sufficient dissolved oxygen. This does not mean that during denitrification low dissolved oxygen values would occur in the plant effluent or the upper portions of the plant's clarification compartment. Indeed, during denitrification such dissolved oxygen values were found to be only slightly lower than at other times. Denitrification, therefore, is a function of

the respiration rate of the organisms contained in the settling sludge, the dissolved oxygen present in the immediate vicinity of the organisms, and the availability of nitrite and nitrate in the liquor surrounding the organisms. For these reasons another control method would be to reduce the residence time of the organisms in the settling compartment so that they were being returned to the aeration compartment while they still had an adequate supply of dissolved oxygen available in their vicinity. This method has certain distinct limitations as will be shown in the section of this report on clarification. A third method was also found to be helpful but since this involved the maintenance of very high dissolved oxygen levels in the aeration compartment, in the hope that such levels would be sufficient to permit a more normal sludge residence time in the clarification compartment, the economics of the situation, however, would not seem to favor such an approach.

The problem of nitrification-denitrification becomes most acute when the pattern of unit loading involves high and low or no flow periods such as that which occurs with school installations. In such cases, unless steps are taken to avoid it, nitrate builds up to high levels within the system during low or no flow periods. During high flow periods bacterial respiration may still be somewhat elevated at the time the organisms enter the clarification compartment resulting in the rapid depletion of dissolved oxygen and the breakdown of relatively large amounts of nitrate with subsequent nitrogen flotation of solids. Under such circumstances, flotation of solids occurred during laboratory settling rate tests conducted on the mixed liquor in less than thirty minutes. To overcome this difficulty, many of the plants used in this study were equipped with timers in the air blower power circuit so that one or more blowers could be automatically turned off or on at a predetermined time corresponding to the peaks and valleys of the loading level pattern. The use of such timers to adjust the air input more closely to the loading of the treatment units proved most beneficial in combating the nitrification-denitrification problem.

The importance of aeration system flexibility is also obvious during the startup period especially if the plant has not been seeded. During the time the plant is building up mixed liquor solids its oxygen demand is increasing due to the increasing removal of BOD. Due to this more air is required to keep the aerator solids in suspension than is desired from a process standpoint. As the process approaches maturity this imbalance becomes somewhat less and more easily controlled. However, during startup without seeding nitrification-denitrification becomes a

problem unless oxygen transfer can be controlled and unless some means of retaining solids in the system is provided the loss of solids in the plant's effluent will perpetuate the problem and result in very long startup times. During the Fall-Winter study two of the ten plants were not equipped with a baffle ahead of their final effluent weir, nitrification-denitrification became a problem during startup, and large solids losses occurred. It was only with considerable difficulty that these two plants were nursed through this period, however, like all the other plants, once they had achieved mixed liquor solids levels of approximately 2,500 mg/l the quality of their effluents became nearly the same as those from the other plants. It is therefore recommended that all plants be equipped with weirs and/or other devices designed to control the loss of solids from the system during periods of startup and/or denitrification.

SOLIDS SEPARATION

Nearly all applied BOD is removed from the raw waste in the aeration compartment of a package sewage treatment plant of the extended aeration type. The effluent BOD from such plants is due, almost entirely, to the endogenous respiration of the organisms in the effluent. Therefore, the overall plant efficiency is dependent on the efficiency of the plant's solid-liquid separation or settling compartment. The efficiency of this compartment is, of course, design dependent.

Periodic losses of solids have frequently been noted in connection with the operation of package and conventional activated sludge plants alike which result in significant reduction in overall process efficiency. Such losses are a function of the settling rate of the solids and the hydraulic load applied to the settling compartment.

When mixed liquor is allowed to settle the contained solids settling rate is at first constant and uniform creating a rather discrete solids-liquid interface, see Figure 42. If the height of this interface is measured and plotted versus time, the zone settling rate for the particular activated sludge so tested can be computed. Activated sludge from domestic waste treatment plants commonly display zone settling rates of from 20 to 30 ft/hr at a concentration of 1,000 mg/l MLSS down to 5 to 6 ft/hr at a concentration of 4,000 mg/l MLSS, see Figure 43. Therefore, as the MLSS concentration increases the zone settling rate decreases until a point is reached where, for all practical purposes, no sedimentation occurs. Aside from the matter of concentration dependency, a particular sludge's zone settling rate is further influenced by the biological and physio-chemical characteristics of the particular system such as the food to microorganism ratio,

intensity of aeration, period of aeration, and similar factors.

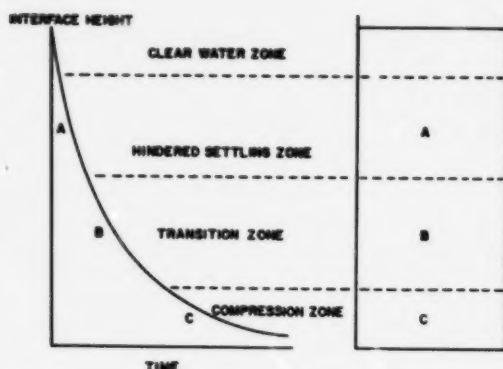


Fig. 42. Zone Settling Rate, Activated Sludge

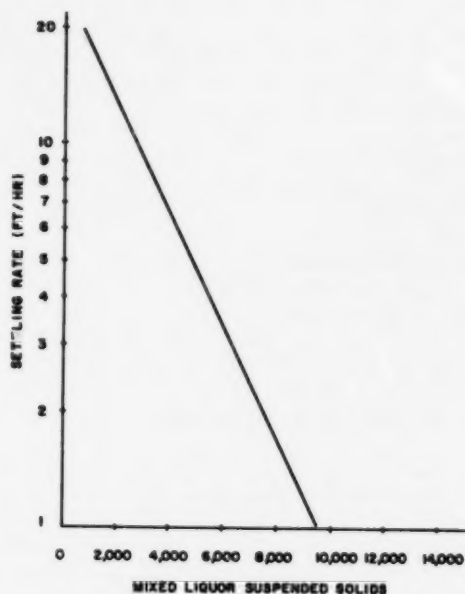


Fig. 43. Zone Settling Rate, Activated Sludge

The zone settling rate concept is perhaps more meaningful when expressed as the equivalent surface overflow rate since if the settling rate is exceeded by the overflow rate resulting from the applied hydraulic loading, solids will be swept out of the plant.

$$O_R = V_s \times 7.5 \text{ gal/ft}^3 \times 24 \text{ hr/day} = V_s \times 180 \quad (16)$$

Where: O_R = Equivalent surface overflow rate (gal/ft²/day)

V_s = Zone Settling Rate (ft/hr)

EXAMPLES

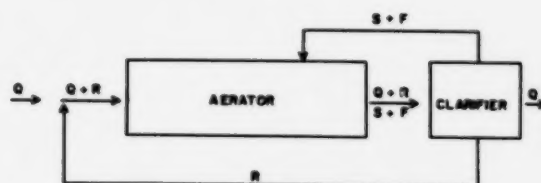
a. $MLSS = 4,000 \text{ mg/l}$ $V_s = 5 \text{ ft/hr}$

$$O_R = 5 \times 180 = 900 \text{ gal/ft}^2/\text{day}$$

b. $MLSS = 1,500 \text{ mg/l}$ $V_s = 15 \text{ ft/hr}$

$$O_R = 15 \times 180 = 2,700 \text{ gal/ft}^2/\text{day}$$

The flow rates at various points in a typical extended aeration package treatment plant are illustrated in Figure 44.



WHERE: Q = INFLUENT FLOW RATE
 R = RETURN SLUDGE RATE
 S = SCUM RETURN RATE
 F = FOAM SPRAY RATE

Fig. 44. Flow Rates, Typical Extended Aeration Plant

For a typical extended aeration package sewage treatment plant receiving its design daily flow, the mean flow will be:

$$Q_m = \frac{V_t}{T} \dots \dots \dots (17)$$

Where: Q_m = Mean Influent Rate (gal/min)
 V_t = Total Applied Waste Volume (gal/day)
 T = Time (min/day)

However, the flow is rarely applied over the total 24 hour period of a day. Most of the flow from a subdivision, for instance, is applied over a period of 16 hours. In the case of a subdivision, therefore, a more realistic value for Q_m would be obtained by:

$$Q_m = \frac{V_t}{T \times 0.66} \dots \dots \dots (18)$$

Further, the influent applied flow tends to follow a regular pattern for a given application and in the case of subdivisions peak flows of 3-4 times the mean value occur with some frequency each day. Since these peak flows are of the greatest importance here, the equation for Q_m needs to be modified further as:

$$Q_m = \frac{V_t}{T \times 0.66 \times 0.33} \dots\dots\dots (19)$$

For a 10,000 gpd plant the importance of these factors can be seen from the following example:

$$Q_m = \frac{10,000}{1,440} = 7 \text{ gpm}$$

$$Q_m = \frac{10,000}{1,440 \times 0.66 \times 0.33} = 32 \text{ gpm}$$

From the discussion of flow rates at various points in a plant we can see that as far as the final settling compartment is concerned this rate of flow is further increased by the use of the scum return and foam control equipment both of which increase the surface overflow rate and oppose the sludge settling rate. If the foam control and scum return equipment were operated continuously this could easily add another ten gallons/minute or more to the surface overflow.

For the purpose of illustration in the present case we will assume that the total clarifier overflow is 45 gpm with some frequency during each day. While clarifier surface areas vary from manufacturer to manufacturer to a certain extent, we will here assume a 10,000 gpd plant having a clarifier surface area of 78.5 ft². At 45 gpm the surface overflow rate would be:

$$O_r = \frac{45 \times 1,440}{78.5} = 825 \text{ gal/ft}^2/\text{day}$$

If the MLSS concentration for this plant is 5,000 mg/l and the zone settling rate for this sludge is 4 ft/hr, then the equivalent overflow rate would be:

$$O_r = 180 \times 4 = 720 \text{ gal/ft}^2/\text{day}$$

From the foregoing it is clear that solids would likely be discharged from this plant during peak daily flows. However, if we had only looked at the theoretical mean influent flow rates we would have had:

$$O_r = \frac{7 \times 1,440}{78.5} = 129 \text{ gal/ft}^2/\text{day}$$

It is then obvious that the true flow rate to the clarifier in this case is approximately 6 times the theoretical value (based on mean influent flow, above) and equally obvious is the fact that unless sludge were wasted from this system, the situation would continue to deteriorate as the MLSS concentration increased.

Proper design of the clarifier portion of an extended aeration package plant must, therefore, take into consideration, among other things:

- (a) The adjusted influent flow rate
- (b) Peak flow rates expected
- (c) MLSS concentration to be maintained
- (d) Use of foam control and scum return equipment
- (e) Biological and physio-chemical characteristics of the system expected

From an operational viewpoint, the zone settling rate and the surface overflow rate can be compared as follows:

$$\frac{V_s \text{ (ft/hr)} \times 7.5 \text{ gal/ft}^3}{Q \text{ (gal/hr)}} = \frac{V_s \text{ (gal/ft}^2/\text{hr)}}{O \text{ (gal/ft}^2/\text{hr)}} \quad (20)$$

$SA \text{ (ft}^2\text{)}$

If V_s/O_r is significantly greater than 1.0 excessive amounts of solids will not be swept out of the system, however, if it is significantly less than 1.0 loss of solids will occur.

EXAMPLE

Given: MLSS = 7,500 mg/l

$$Q = 24 \text{ hr mean} = 10,000 \text{ gpd}/24 \text{ hr} = 416 \text{ gph}$$

$$SA = 78.5 \text{ ft}^2$$

$$V_s = 2 \text{ ft/hr}$$

$$\frac{2 \times 7.5}{416} = \frac{15.0}{5.3} = 2.83$$

78.5

If, however, the comparison is made on the basis of the peak flow rate being three times the average rate and all flow is received during an 18 hour period each day and, further, if the foam sprays and skimmer are operated constantly, we would have:

$$\frac{2 \times 7.5}{(3 \times 556) + 10} = \frac{15}{78.5} = 0.7$$

For the preceeding example the maximum allowable MLSS concentration would be less than:

$$\frac{7.5 (X)}{21} = 1 \dots\dots\dots(21)$$

$$x = 2.8 \text{ ft/hr} = 6,500 \text{ mg/l approx.}$$

McKinney²³ has related the maximum MLSS concentration that can be maintained in the aeration tank to the sludge density index of the MLSS as follows:

$$M_t = \frac{(SDI) (10,000)}{\frac{1}{r} + 1} \dots\dots\dots(22)$$

Where: SDI = Sludge Density Index
r = Recirculation Ratio

EXAMPLES

$$SDI = 1.0$$

$$M_t = \frac{(1) (10,000)}{\frac{1}{3} + 1} = 7,500 \text{ mg/l}$$

$$SDI = 0.50$$

$$M_t = \frac{(0.50) (10,000)}{\frac{1}{3} + 1} = 3,750 \text{ mg/l}$$

However, at high MLSS values the compression zone represents a large percentage of the total 30 minutes settling time and the SDI derived from the data is not reliable. It has been found that if a high MLSS mixed liquor is diluted with various amounts of clear effluent from the same plant and the mixtures are allowed to settle for 30 minutes, the suspended solids concentrations for the mixtures determined, and the SDI for each mixture derived, the derived values may vary over a fairly wide range, see Figure 45.

This difficulty was noted by Orford, Heuklelian, and Isenberg²⁵ who adjusted the solids content of the sludges tested to 1,000-1,500 mg/l to eliminate the effect of solids concentration on the test result. The importance of making such an adjustment in the test procedure can be seen when one attempts to relate sludge density index to sludge loading. In terms of the loadings encountered in conventional activated sludge plants sludge density index decreases with increasing loadings, however, as was shown by Orford *et al*²⁵, below a loading of 0.17 lb. BOD/lb. MLVSS/day, sludge density decreases with decreasing loadings. But, at loadings below 0.05 lb. BOD/lb. MLVSS/day

the trend apparently again reverses unless the solids concentration of the mixed liquor being tested is adjusted prior to conducting the settling test. In terms of mixed liquor suspended solids, this second reversed occurs at about 4,500 mg/l. When both adjusted and unadjusted data is plotted two distinctly different curves are obtained as can be seen in Figure 46.

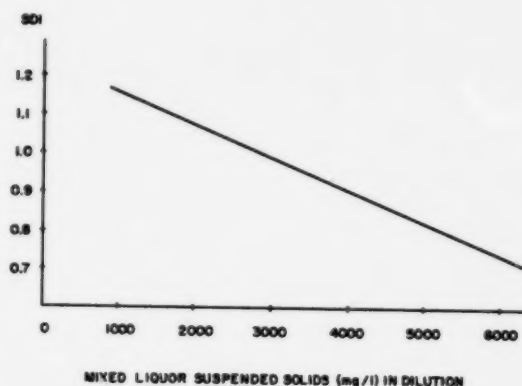


Fig. 45. SDI Values for Various Dilutions, Plant C-1

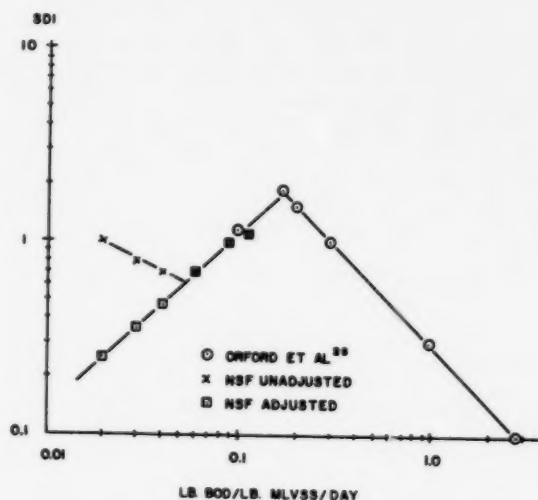


Fig. 46. Sludge Loading and Sludge Density Index, Fourteen Plants (1,526 Plant Days)

While the volume of return sludge, which is withdrawn from the final clarifier at or near the bottom of the compartment and which reappears in the clarifier influent as an increased volume of mixed liquor, cannot be considered as having a direct upflow potential or be expressed as equivalent overflow rate it does create turbulence and movement in the clarifier which can, to some

extent, act to offset a portion of the sludge settling rate which might otherwise occur. This is especially true of very high sludge return rates. Many manufacturers have combated this problem by the use of baffles and stilling wells at the point where the mixed liquor enters the clarifier. Nevertheless, in general, it is well to operate with as low a return sludge rate as practical consistent with the other demands of the process and system involved. This is perhaps the best argument against the use of high return sludge rates to help combat the denitrification problem outlined in a previous section of this report.

During these studies suspended solids removals for all plants under all conditions of loading, with but one exception, were 80 percent or greater based on mean influent and effluent values, see tables. The exception to this was the pair of plants operated at maximum loading on a school flow pattern during the Spring-Summer studies. It is believed that this flow pattern overtaxed the capabilities of these plants' solids separation systems and that under such hydraulic loading the solids separation systems became the dominant process efficiency limiting factor.

SKIMMING

All of the plants utilized in these studies were equipped with skimming devices designed to remove floatables from the surface of their clarification or solids separation compartments. During the early phases of the study these skimmers were operated continuously. As the mixed liquor suspended solids concentration increased in these plants the upflow potential created by the continuous skimming began to assume the role of an important process efficiency limiting factor. Solids were pulled upward by the skimmers and once resuspended in the upper portion of the clarifier were being swept out of the plants in their effluents.

At first attempts were made to reduce this effect by reducing the skimming rate and by adjusting the tops of the skimmers to as near the surface of the water as practical. These adjustments reduced the problem for a time but did not entirely eliminate it. As the solids concentration in the units continued to increase, it became more difficult to so adjust the skimmers so as to avoid the problem and it was finally decided to try operating them only once or twice a day. This periodic operation of the skimmers virtually ended the problem of solids losses from the system due to the skimmers but it also resulted in the accumulation of floatables on the surface of the clarifiers between skimmings in those plants equipped with a baffle ahead of their effluent weir, (see the section of this report on nitrification).

While the presence of floatables on the surface of the clarifiers between skimmings may render the plants less aesthetically pleasing than otherwise, it was concluded that process efficiency must be given precedence in this case. It is recommended that all plants be designed to retain floatables within the system and that clarifier skimming be provided for with such flexibility as to permit the plant operator to adjust the rate of skimming or to shut it off entirely as required.

TEMPERATURE

During these studies package sewage treatment plants of the extended aeration type were operated during both Summer and Winter to determine, among other things, the effect of temperature on process efficiency.

During the Fall-Winter studies the mean aerator contents temperature for all plants was 11.4°C while during the Spring-Summer studies the mean aerator contents temperature for all plants was 18.0°C or above, see tables. Since some plant pairs in the Spring-Summer studies were started later in the season than others, a range of mean temperatures from 18.0 to 23.3°C was encountered.

At one point in the Fall-Winter studies the aerator contents temperature of several plants fell to low values of 3-4°C for some days due to the long (twenty-four hour) aeration period involved and the temperature of the air being blown through the aerator contents. During this period no significant loss of BOD₅ removal efficiency was experienced. The plants had been operating with mixed liquor solids concentrations above 2,500 mg/l for some time prior to the onset of very cold weather (ambient temperatures of 0°C or less) and it will be recalled from the preceding discussion of BOD₅ removal that such combinations of solids and time is equivalent to an $S_a T$ value of 60×10^3 or greater. Further, for a 10°C decrease in process temperature the oxidation rate of the organisms involved would be reduced by half which is the same as having one half as many organisms operating at the former rate or $S_a T$ values of 30×10^3 or more which is more than adequate for a 90 percent BOD₅ removal. Indeed, far fewer organisms or a much lower rate of activity would still be expected to produce a 90 percent removal. Therefore, it is not surprising that the BOD₅ removal efficiency of the systems did not suffer significantly during periods of low process temperature.

It was noted, however, that in the case of those plants which reached low process temperatures nitrification was reduced and in the most severe cases of low temperature nitrification

ceased altogether, see Figure 47. This occurred despite the fact that residual dissolved oxygen values in the aeration compartment of the plants was at least as high, and in most cases higher, than during periods of higher process temperatures.

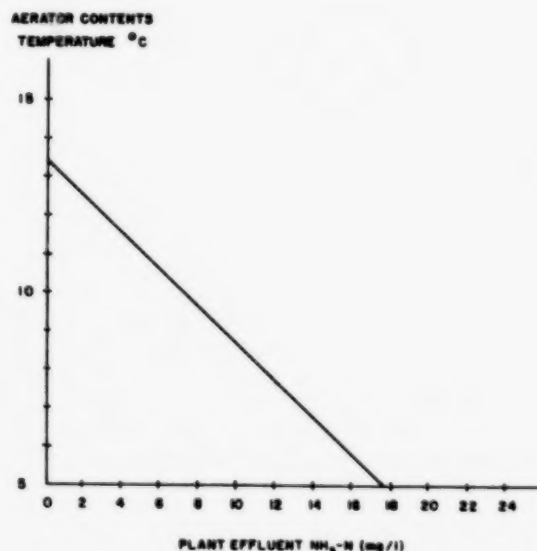


Fig. 47. Nitrification-Plant A-I, Fall-Winter Studies

During the Spring-Summer studies effluent ammonia-nitrogen values for mature plants having an aerator contents residual dissolved oxygen value of 1-2 mg/l were zero.

In order to provide at least some weather protection for the steel tank package plants used during the Fall-Winter studies bales of hay and straw were piled around the hopper portion of each plant. While this did not result in the same degree of protection as that afforded by below grade installation, it did, under the operating protocol employed, prevent any interruptions in plant operations due to freezing.

OPTIMUM MIXED LIQUOR SOLIDS

As was pointed out previously, sustained BOD_5 removals of 90 percent or better were not found to be generally associated with mixed liquor suspended solids levels much below 2,500 mg/l. While it is true that for aeration periods of twenty-four hours mixed liquor solids concentrations of considerably less than 2,500 mg/l should suffice to remove substantially more than 90 percent of the applied BOD_5 , we are not concerned here with specifically the removal of substrate in the aeration compartment of package plants but rather

the overall apparent BOD_5 and suspended solids removal of the plants.

The reason for the apparent difference between the theoretical removals and the observed removals is, of course, that, as has been shown, the influent solids and BOD are not strictly speaking the same thing as those in the effluent of the plant. The overall or apparent removals, especially during the plant startup period, are a function of the rapidly changing food to microorganism ratio which affects the settling rate of the solids and the rapidly changing solids concentration itself which, as was noted earlier in this report, affects the settling rate. At high food to microorganism ratios solids flocculation is not as pronounced as at somewhat lower values and respiration rates are higher. Further, at solids concentrations much below 1,000 mg/l the activated sludge particles do not settle as a mass (zone settling) but rather as discrete particles with each settling at its own rate essentially independent of the other particles around it. All of these things combine during startup to result in apparently lower than theoretical removals of solids and BOD .

From an overall viewpoint, then, it is not desirable to operate extended aeration package sewage treatment plants at less than 2,500 mg/l mixed liquor suspended solids. This is not to say that any solids concentration value above this level is desirable. It has been shown that zone settling rate is dependent on, among other things, the concentration of solids and that relatively small increases in solids concentration can significantly lower the settling rate. Since there is a minimum permissible settling rate for any given plant below which apparent overall process efficiency is impaired then there is a corresponding upper limit on the mixed liquor suspended solids concentration which should be carried in the plant in order to achieve maximum efficiency. In general, it does not appear desirable to maintain a mixed liquor suspended solids concentration much in excess of 6,000 mg/l. Indeed, a solids concentration of 4,000 mg/l would appear to be an ideal target from an operational viewpoint. This operational target would give sufficient leeway on both the higher and lower sides to admit of sustained removal efficiencies of the desired magnitude.

SOLIDS WASTING

It has been shown in other portions of this report that solids accumulate in extended aeration package sewage treatment plants. This accumulation is the result of the retention of inert solids entering the plant in the raw waste, and the accumulation and retention of the inert solid and products of endogenous respiration together with the synthesis of new biological solids. This

accumulation will continue until the plant's capacity for solids retention is reached after which the excess solids will be discharged in the effluent. Where an intermediate level of treatment is desired the excess solids may be allowed to dispose of themselves in the effluent, however, if sustained high level treatment is desired then solids wasting must be practiced.

For extended aeration plants being fed domestic wastes at or below design level and maintaining a mixed liquor suspended solids level between 2,500 and 6,000 mg/l, the problem of solids wasting would not appear to be a particularly great one. During the Fall-Winter studies which lasted about seven months, it was not necessary to waste sludge from any of the plants in order to maintain sustained high process efficiency. At the end of the Fall-Winter studies all but two of the ten plants were drained and cleaned. The other two plants were continued in operation mainly to determine at what point it would be necessary to waste solids in order to maintain high process efficiency. After approximately ten months of continuous operation at design load it became necessary to waste solids from one of the two plants which had by that time attained a mixed liquor suspended solids concentration of 9,840 mg/l. During these ten months this plant had been operated steady state with respect to flow which permitted a buildup of solids to this level without impairing process efficiency. After reducing the mixed liquor suspended solids level to nearly 4,000 mg/l this plant was again allowed to accumulate solids while being operated on a subdivision flow pattern at design loading. On this flow pattern it was necessary to waste solids at a mixed liquor solids concentration of 7,480 mg/l in order to maintain treatment efficiency.

Frequent sludge wasting is not desirable from several standpoints. First, the solids accumulation (lb/lb BOD Removed) is less at higher solids levels, see Figure 37. Second, sludge wasting creates an ultimate disposal problem in that it must either be trucked to a suitable disposal site or applied to sand beds which must eventually be raked and otherwise cared for. In the case of plants treating domestic waste at or below design load it would not appear that wasting would be required more than two or three times a year. For domestic wastes containing unusual amounts of inert solids and for certain commercial or industrial wastes more frequent wasting will be required.

ROUTINE OPERATION AND MAINTENANCE

Much has been said and written about the importance of maintenance and operation in connec-

tion with package treatment plants. The experience gained during the present studies points up the importance of this but perhaps in a different way than is generally thought. Manufacturers of extended aeration package plants commonly advocate a minimum of one hour per day for combined maintenance and operation. An analysis of the research site records indicates that this amount of time should be adequate in most cases. It was the opinion of the staff members who operated these plants that it is not a matter of the time involved *per se*, but rather the degree of conscientiousness displayed by the operator during that time. Further, it is obvious that conscientiousness alone is not enough but rather that this trait must be combined with a reasonable knowledge of the mechanics of the process and at least some appreciation of the capabilities and limitations of the organisms involved.

The foregoing can be taken as evidence that the process efficiency of an extended aeration package plant which receives an hour of conscientious attention every day should not be limited by this factor.

As a check list for normal maintenance and operations the following is suggested:

CHECK LIST FOR ROUTINE MAINTENANCE AND OPERATIONS EXTENDED AERATION PACKAGE SEWAGE TREATMENT PLANTS

1. Determine that power is being supplied the unit and that all pumps and motors are operating or operational as required.
2. Grease and oil equipment, clean air filters, check pressure relief valves, and perform related work as recommended by the manufacturer.
3. Hose down walkways, sideboard, and splash-spray zones as needed.
4. Check air lifts and return lines for clogging.
5. Operate skimming device(s) as needed.
6. Perform recommended simple laboratory analytical procedures and adjust operating variables as indicated. The recommended or required analytical procedures for a given plant may include but are not necessarily limited to, any or all of the following depending on the requirements of the particular regulatory agency having jurisdiction and the needs of the installation:
 - a. Influent, effluent, mixed liquor, and return sludge suspended and volatile suspended solids. (Rapid photometric methods for the determination of suspended solids have been found to be reliable.)

- b. Influent and effluent five day biochemical oxygen demand. Effluent BOD₅ values can be approximated through correlation with suspended solids values if the oxygen uptake rate of the solids is known. A modified chemical oxygen demand test has also been shown to closely approximate these values.)
- c. Mixed liquor and effluent dissolved oxygen concentration.
- d. Influent, mixed liquor, and effluent pH and temperature values.
- e. Mixed liquor thirty minute settled volume determination (SV₃₀).
- f. Mixed liquor oxygen uptake rate.
7. If effluent disinfection is required, insure that an adequate supply of disinfectant is available and that the feed device is operating properly.
8. Scrape down the insides of clarifier hopper at least daily and/or determine that sludge collection mechanisms are operating properly depending on the design of the plant.
9. Remove litter from the plant area and perform grounds keeping operations as required.
10. Repaint exposed painted surfaces as needed.
11. Inspect aeration equipment thoroughly including diffusers, impellers, and the like which may be submerged. While this may not need to be done as frequently as some other items of maintenance, it should not be overlooked and the manufacturer's recommendations should be carefully followed.
12. Remove and dispose of in a sanitary manner any material that may accumulate on inlet bar screens and the like. Check and clean the comminutor if one is a part of the plant.
13. Check, clean, and maintain any such plant support units such as a sand bed, sludge holding tank, trash trap, and the like.
14. Replace worn parts and/or equipment as needed. Pay particular attention to pulley belts and the like which may require relatively frequent replacement. Maintain a small stock of such items including belts, fuses, heaters, and similar items which are essential to plant operation.
15. Waste solids from the system as required to maintain the solids within the desired range.

It should be emphasized that daily and conscientious maintenance and operational attention is required in order to achieve the certified level of performance.

During these studies the operating staff found that some maintenance time could be saved by having at least two air filters on hand for each plant. This permitted the replacement of a dirty filter with a clean one on a regular basis and the cleaning of the dirty filter at a time when other duties were less pressing. Further, the dirty filters could be soaked in cleaning solvent for some time thus rendering the job less difficult.

When the operator first went on a plant each day during this work he would turn on the skimming device and allow it to operate during the time he was working on the plant. Other operational and maintenance items were performed in sequence according to a regular routine which in itself saves time through the efficient organization of the work to be performed. The last item of the daily routine was to turn off the skimming device.

It was not found necessary to hose down the plant each day especially after the plant's mixed liquor suspended solids concentration reached 1,700 mg/l since at about this point foaming of the aerator contents was suppressed. It was found that after the startup period a complete cleanup of the plants once each week was sufficient especially if a partial cleanup was performed daily as required.

After the mixed liquor solids reach 2,500 mg/l it was found that it was not necessary to scrape the hopper portion of the clarifiers as frequently as during the startup period. In general, daily scraping was required during startup with the necessity for this decreasing as the process approached maturity. After the aerator solids concentration reached 2,500 mg/l it was necessary to scrape the hoppers only about once a week.

Very little problem was encountered during these studies with diffuser clogging.

No process support equipment such as blowers, pumps, air lifts, or the like failed during the course of this work. It was found that even under the somewhat adverse conditions of above grade operation during the Michigan winter, a regular program of cleaning, greasing, oiling, and checking sufficed to enable relatively trouble free operation of the plant involved.

During several periods the plants were neglected and this resulted in significant efficiency losses. Routine, conscientious, and knowledgeable operation and maintenance is, therefore, strongly recommended to achieve maximum efficiency.

One major problem which was encountered during this work resulted from momentary power interruptions such as occur from time to time during thunderstorms. When such momentary interruptions occurred the electrical circuit within the plants would be broken and the plants would have to be manually restarted. This was no problem so long as the plants were attended at the time of the interruption, however, when this occurred at night or other times when the plants were not attended a considerable amount of time elapsed before the plants were restarted. Of course, during such periods treatment efficiency fell markedly. This problem was also noted by Schwing³⁹ in connection with his supervision of a number of package plants in the field.

BACTERIOLOGICAL

At one point in these studies effluent samples from two of the plants were examined bacteriologically for a total of 45 days. All determinations were by membrane filter techniques. Both plants were loaded at design levels during this period. The average results obtained were as follows:

Plant A-2

	Organisms/100 ml.
1. Enterococci	8,000
2. Coliforms	97,250
3. Total Count	850,000

Plant C-1

1. Enterococci	1,360
2. Coliforms	45,500
3. Total Count	161,000

It was found that both the total and enterococci count varied directly with the effluent suspended solids. The coliform count followed essentially this pattern but was more variable in this respect. No difficulty would be anticipated in reducing these bacterial numbers to desirable levels through the use of appropriate bactericidal agents and dependable application devices.

PLANT SIZE AND CONSTRUCTION

In order to determine the effect of plant size and materials of construction on performance ten package sewage treatment plants of the extended aeration type were operated at maximum design load, steady state hydraulic conditions, on the same domestic waste feed, under the same conditions of temperature and operation, at the same

time. The results of this study indicate that where size is the only variable and when there is an observed difference in performance the lowest efficiency will be associated with the smallest size plant. Under the conditions of the test described above the following results were obtained based on mean values for all plants of a given size range:

SIZE (gpd)	BOD REMOVAL (%)
5,000 - 7,000	88
7,500 - 9,000	89
10,000 - 14,000	91
15,000 - 20,000	94

Plants constructed of steel and concrete were both utilized in these studies. A comparison of overall process efficiency by both types of plants of the same daily waste treatment capacity under identical conditions of loading and operation failed to disclose any significant differences in the results obtained. It was, therefore, concluded that the material of construction is not of itself a factor limiting overall process efficiency so long as the unit is structurally sound.

RAPID ANALYTICAL METHODS

Throughout these studies an attempt was made to find relatively quick, simple, and meaningful test methods which could be used both to operate and to determine the performance of extended aeration package plants. Once it became clear that the concentration of BOD₅ in the effluent of these plants was due almost entirely to the respiration rate of the organisms contained in the effluent solids it became equally clear that the plant's performance could be judged on the basis of effluent quality in terms of suspended solids. What was then needed in the field was some rapid and reliable method of determining the suspended solids present in the plant effluent. An additional need was the ability to determine the respiration rate of those solids.

At least as early as 1940 a relationship had been noted between turbidity and BOD₅ values for several wastes⁴⁰. Eckenfelder⁴¹ advocated the use of photometric methods for the rapid estimation of process efficiency in 1952. Krawczyk and Gonglewski⁴² described an accurate and rapid suspended solids determination method using a spectrophotometer in 1959. McTavish⁴³ published a similar method in 1965. The information contained in these papers was studied and the methods

advocated were investigated by the Foundation's Research Site Staff who found as follows:

1. Samples containing readily settleable solids should be blended at high speed for two minutes prior to testing.
2. After blending, if needed, the sample's absorbance or transmittance should be read in a spectrophotometer using a one inch sample container against a distilled water blank, at 950 millimicrons.
3. A calibration curve for the particular instrument and sample container employed should be made by plotting STANDARD METHODS³⁷ and corresponding spectrophotometer data for a number of samples.
4. The relationship of solids concentration to absorbancy was found to be lineal thus obeying the Lambert-Beer law over the range of zero to three hundred fifty mg/l suspended solids.
5. Samples having a suspended solids content in excess of 350 mg/l should be diluted prior to blending so that the solids content of the sample read in the instrument falls within the range investigated.
6. Suspended solids in samples of mixed liquor, return sludge, and plant effluent can be determined with equal accuracy.
7. Small, battery operated instruments which are presently available can be used without blending the samples in the field with sufficient accuracy to determine the quality of package plant effluents and to determine the level of solids at various points in the process as an aid to plant operation and supervision. When samples are not blended a separate calibration curve will be required for them and such samples should be read as soon as they are placed in the instrument. Of course, thorough mixing of the sample just before placing it in the instrument is required.

Dissolved oxygen levels at various points in the process can be determined with high precision and accuracy by any one of several battery powered dissolved oxygen analyzers which are available. These same instruments can be used in the field to determine the oxygen uptake rate of the mixed liquor solids according to the methods of Eckenfelder and O'Connor³⁸.

The total cost of the two battery powered instruments (spectrophotometer and dissolved oxygen analyzer) is presently about \$500.00 which would appear to make this a reasonable invest-

ment for anyone who supervises or operates several package plants or perhaps even one plant of relatively large size.

Since it had been found that effluent suspended solids could be determined with considerable accuracy using photometric methods it seemed reasonable to assume that one of the presently available flow through turbidity meters could be used to continuously monitor and record plant effluent suspended solids. Such a unit was installed on one of the plants and operated for a period of some months. For suspended solids concentrations above 20 mg/l reasonably good correlation with STANDARD METHODS³⁷ solids determinations was obtained. Below a solids concentration of 20 mg/l considerable variation was encountered probably due to entrained air in the sample registering on the instrument and the decreasing precision and accuracy of the standard method with decreasing solids concentrations. It was assumed that a somewhat less sensitive instrument might have yielded a better correlation with the standard method.

Nevertheless, it was obvious that since little adverse sanitary significance would likely be attached to an effluent having a suspended solids concentration of 20 mg/l even the instrument used would have value in monitoring the performance of package plants in remote locations. By utilizing a hookup to the telephone line system such units could be readout by supervising personnel at some central office or the instrument could transmit an alarm signal when the effluent suspended solids reached some predetermined upper limit. Such readout and alarm systems could be readily assembled using standard parts and equipment presently available.

Another interesting rapid analytical procedure is the Oxygen Demand Index method developed by Westerhold⁴⁴. This method is a rapid chemical oxygen demand test which can be completed in about thirty five minutes and which yields a value for ordinary domestic wastes and plant effluents which closely approximates the BOD₅ value. Anyone equipped with a spectrophotometer, either line operated or battery powered, could make this determination. Actually, the person conducting the test would only be involved about five minutes out of the total of thirty five since most of the required time is for heating the sample.

Many workers in this field have advocated the use of a thirty minute settling test as a prime operational guide. Such a test is often used both to judge the volume of solids in the aeration system and the quality of the plant's effluent. In the latter case, this method is, in the final analysis,

based on the same reasoning as the photometric method advocated earlier in this section. It should be borne in mind, however, that it was shown in another section of this report that the sludge volume index is not strictly reliable at the relatively high mixed liquor suspended solids levels generally associated with extended aeration plants. The thirty minute settling test or Sludge Volume Thirty (SV₃₀) as it was named during these studies is dependent to a certain extent on the size and configuration of the vessel in which it is conducted. If portions of a mixed liquor having a suspended solids concentration of 4,000-5,000 mg/l are settled for thirty minutes in a 500 ml. graduated cylinder, a 1,000 ml. graduated cylinder, a quart jar, and a three liter battery jar a series of results will be obtained which illustrate a portion of the problem and which explain why such laboratory tests sometimes indicate that a certain state of affairs exists within the plant which the observed plant operation fails to bear out. It can be said that, in general, the closer the proportions of the test vessel with respect to surface area and depth ratio approaches the proportions of the settling compartment of the plant the greater will be the direct correlation between the two. Of the laboratory equipment readily available, the three liter battery jar is perhaps the best choice for SV₃₀ determinations.

STANDARD ANALYTICAL METHODS AND SAMPLES

In a study such as the present one which involves the monitoring of a large number of plants being operated under a variety of carefully controlled conditions and which utilizes nearly all of the important sanitary chemistry standard methods it is possible to make some judgements as to the importance of various types and classes of data in the performance evaluation of those plants. Such judgements have been made in the present case and are embodied in the following items:

1. Influent and effluent BOD₅ tests serve as the basic performance evaluation technique and should be conducted frequently during the evaluation.
2. Influent and effluent COD test values serve as a good basic check on the BOD₅ determinations since the removal of COD has been observed to vary with the removal of BOD₅.
3. Influent and effluent suspended and volatile suspended solids should be determined frequently during the period of plant evaluation since these tests serve as another basic performance evaluation technique and since effluent solids values

have been shown to be directly related to effluent BOD values.

4. Influent and effluent pH values should be determined during plant evaluation since the change in pH values through the plant serves to assist in defining the state of the process and the influent value serves to assist in defining the waste being treated.
5. Influent and effluent alkalinity values should be determined frequently during the evaluation period since the change in this value is related to the degree of nitrification and thus serves as a check on nitrogen changes through the plant.
6. Influent and effluent ammonia-nitrogen data should be frequently collected during the evaluation since the change in this value through the plant is related to, among other things, the net state of the process and especially to the time and intensity of aeration.
7. For plants being evaluated on domestic wastes the influent nitrate and nitrite-nitrogen levels are of doubtful value in performance evaluation since such values are generally quite low if indeed any nitrogen is present in this form. However, effluent nitrate values are most important both as they relate to the net change in ammonia-nitrogen values and the factors affecting those values but also as they assist in assessing the potential impact of the plant effluent on the receiving waters. Effluent nitrite values are considered of minor significance since nitrite exists as an intermediate form between ammonia and nitrate-nitrogen and generally is present in the plant effluent in small amounts.
8. Influent and effluent phosphate values are important in evaluating the removal of this important nutrient from the waste feed and in assessing the potential impact of the plant effluent on the receiving waters.
9. Influent dissolved oxygen values are not considered of significance in performance evaluation since the weight of oxygen in the raw waste feed is too small to have any significant effect on plant operations or performance. Effluent dissolved oxygen values are important in assessing the potential impact of the treated wastes on the receiving waters and as a guide to the state of the process embodied in the plant.
10. Influent and effluent methylene blue active substance (MBAS) serve as the best routine guide to the plant's detergent removal

efficiency and, therefore, are important in an evaluation of plant performance.

11. In order to correlate the observed plant efficiency with the state of the plant process the following mixed liquor determinations are recommended:

- a. suspended and volatile suspended solids
- b. residual dissolved oxygen
- c. pH

- d. temperature (it is interesting to note here that the temperature of the raw waste feed is of minor importance because of the relationship of feed volume to aerator contents volume and the temperature of the aerator contents at or below design loading levels approaches the ambient temperature due to the aeration period and quantity of air blown into the aerator contents. The temperature of the effluent is also of minor importance since at design loading effluent temperature and aerator contents temperature will be nearly the same even at relatively low ambient temperatures).

- e. Thirty minute settled volume (it should be noted again here that the results of the SV₃₀ test must be interpreted with caution at relatively high mixed liquor suspended solids values unless the solids contents of the sample being tested is adjusted to approximately 1,500 mg/l in the event of MLSS values significantly above this level).

- f. oxygen uptake rate

12. For the purpose of plant performance evaluation, return sludge tests should be limited to the following:

- a. suspended and volatile suspended solids (these determinations should be conducted with sufficient frequency to fairly evaluate the concentration of solids achieved in the settling compartment. The concentration of solids in the return will be dependent on, among other things, the rate of return).

- b. rate of return (volume/unit time).

- c. thirty minute settled volume (Caution! dilute as required).

13. Both a continuous record of the rate of raw waste application and the total daily application are required to properly evaluate and interpret observed plant performance.

14. Such other tests should be carried out from time to time as may be necessary to evaluate and interpret observed process and performance phenomena.

Both samples composited strictly according to applied waste feed rates and grab samples will be required. All composites should be twenty-four hour samples. For patterned flows both maximum and minimum flow grab samples will be required in some cases. All samples should be handled, preserved, and tested STRICTLY in accordance with the provisions of the latest edition of Standard Methods for the Examination of Water and Wastewater³⁷.

For routine operation and supervision of extended aeration package sewage treatment plants the methods outlined in the preceding section may be found useful and can be employed if proper calibration is employed to take into account the characteristics of the specific process and waste.

III. PERFORMANCE CRITERIA

AND

THE STANDARD PERFORMANCE EVALUATION METHOD

The findings detailed in Section II have been translated into performance evaluation criteria for extended aeration package sewage treatment plants. These criteria are as follows:

1. The plant shall display a sustained mixed liquor suspended solids buildup during the start up period.
2. The plant, when its design loading is not exceeded, shall achieve a sustained design BOD₅ removal after the process reaches maturity.

3. The aeration system shall be capable of transferring sufficient oxygen to meet peak design loads in addition to any other demands made on the system such as maintaining the contents of the aeration compartment completely in suspension, operation of air lifts, and the like.

4. The aeration system, when operating at the midpoint of its rated capacity, shall have such flexibility or admit of such adjustment as to not adversely affect process efficiency.

5. The solids separation system shall be capable of separating and retaining within the plant sufficient solids so as not to adversely affect over-all process efficiency.

6. The floatable solids retention and skimming system shall be capable of retaining and returning to the aeration compartment sufficient floatables in such a way as not to adversely affect over-all process efficiency.

7. When subjected to cold weather operating conditions after reaching process maturity the plant shall achieve essentially the same degree of process efficiency as at other times of the year providing that it and its process support equipment are protected from freezing.

8. The plant shall have such flexibility as to readily permit maintenance of the desired range of mixed liquor suspended solids concentrations.

Based on the fundamentals of the processes involved, the findings of these studies, the investigations of others as cited, and the performance criteria developed, the following method for the evaluation of the performance of extended aeration package sewage treatment plants has been devised:

A. PREQUALIFICATION

1. Prior to the performance evaluation of any extended aeration package sewage treatment plant, the manufacturer of such plant shall supply to the testing agency, group, or organization sufficient evidence to establish to the satisfaction of such agency, group, or organization the basic feasibility of the plant with respect to its intended service.
2. As a part of his application for performance evaluation of a particular plant model or model series the manufacturer shall set forth the basic description of the plant or model series and design data including complete drawings and specifications for the plant and all of its equipment and appurtenances. The application shall be accompanied by a complete installation, operation, and maintenance manual which includes a thorough discussion of the process fundamentals involved.

B. GENERAL TEST CONDITIONS AND REPORTING

1. The waste utilized as feed for the unit during these evaluations shall be a comminuted domestic waste free of any industrial waste which in any way might affect the performance of the plant being tested. Stale or septic sewages shall not

be utilized. The sewage utilized as feed for the plant shall be sampled and tested daily during the test period. The samples shall be twenty-four hour samples composited strictly according to the plant influent flow pattern in use at the time of sampling. Analysis of these samples must establish that the characteristics of the waste utilized as feed during the test conformed to the following:

- a. Five Day Biochemical Oxygen Demand (BOD₅) - a mean concentration based on all data of 200 mg/l plus or minus 30 percent, provided further that none of the samples yield a BOD₅ value of less than 50 mg/l or more than 400 mg/l.
 - b. Suspended Solids (SS) - a mean concentration based on all data of 220 mg/l plus or minus 30 percent provided, further that none of the samples yield an SS value of less than 55 mg/l or more than 440 mg/l.
 - c. Percent Volatile Suspended Solids - no values less than 65 or more than 85 percent.
 - d. Temperature - no values less than ten degrees or more than twenty-five degrees centigrade.
 - e. pH - no values less than pH 6.0 or greater than pH 8.0.
2. All samples shall be strictly taken and preserved as provided in the latest edition of Standard Methods for the Examination of Water and Wastewater³⁷ except as may be otherwise provided herein.
 3. All analytical methods employed shall be those set forth in the latest edition of STANDARD METHODS³⁷ except as may be otherwise provided herein.
 4. During the test period the plant shall be operated and maintained according to the manufacturer's instructions except as these may in any way be in conflict with the provisions of the Standard Performance Evaluation Method in which case the provisions of the Method shall be complied with.
 5. The Standard Evaluation Method can be carried out at any time of the year provided that the plant being tested has reached process maturity as evidenced by a mixed liquor suspended solids concentration of 2,500 mg/l prior to the time that the temperature of the aerator contents falls to 8.0 °C and provided, further, that during

the test period the temperature at no time falls below 5 °C if the test is conducted during cold weather and that the plant and its equipment is protected from freezing. If the test is conducted under warm weather conditions the temperature of the aerator contents shall at no time during the test period exceed 30.0 °C.

6. The performance evaluation of a plant shall be independent of its design and construction except that structural weakness and/or defects and failures of its process support equipment noted during the test shall be reported as a part of the test results.
7. For a series of plants of the same model which vary essentially only in capacity, the results achieved by the smallest plant in the model series shall be taken as indicative of the capabilities of all other plants in the series. In the event that the manufacturer of the model series submits more than one plant in the series for testing, the results achieved by each plant tested shall be taken as indicative of the capabilities of all other larger plants in the model series up to the next larger size tested.
8. The Standard Performance Evaluation Method shall consist of three main parts:
 - a. Startup Performance Evaluation (The period between actual startup of the plant and its achievement of a mixed liquor suspended solids concentration of 2,500 mg/l).
 - b. Subdivision Flow Pattern Performance Evaluation (A period of thirty days beginning with the plant's achievement of a mixed liquor suspended concentration of approximately 2,500 mg/l).
 - c. School Flow Pattern Performance Evaluation (A period of thirty days following the adjustment of the mixed liquor suspended solids concentration to approximately 2,500 mg/l at the end of the subdivision pattern evaluation period).
9. During the performance evaluation phases the plant shall be hydraulically loaded at its rated daily capacity with the pattern of hydraulic loading depending on the requirement set forth for each phase.
10. The information and data developed during each phase will be reported and summarized separately in the certified performance evaluation report.

11. The certified performance evaluation report shall be signed by both the chief administrative officer of the testing organization and the official of the organization in direct responsible charge of the evaluation. The report shall contain but not necessarily be strictly limited to the following:
 - a. A copy of the Standard Performance Evaluation Method.
 - b. All data and information developed during the evaluation in detail. "Summary Data", "Typical Data", and the like shall not be used. This information and data shall be grouped according to the three main parts of the evaluation and used only in the calculation of the results of section to which the data pertains.
 - c. A summary statement of the evaluation results.
 - d. A certification statement signed by the testing organization officials and/or officers specified above which states that the Standard Performance Evaluation Method was used in the testing of the plant, that no deviations from this method were made during the test, and that the results reported are true to the best of their information and belief.

C. STARTUP PERFORMANCE EVALUATION

1. The plant shall be completely assembled according to the manufacturers' directions and all of its equipment checked to determine that it is free of mechanical defects and operable. The plant shall be examined to determine that it is structurally sound. All defects noted shall be reported. If no defects are detected this fact shall be reported.
2. If no defects are detected and the plant is judged to be structurally sound it shall be filled with domestic waste (previously defined under B-1) as rapidly as possible and immediately placed into full operation. Sampling and testing shall begin as soon as the plant is filled and placed into operation and shall continue without interruption until the end of the first two of the three parts of the Standard Performance Evaluation Method.
3. Aerator contents residual dissolved oxygen levels shall be maintained between 1.0 and 2.0 mg/l as nearly as possible. In no case shall the residual dissolved oxygen

level be permitted to fall below 1.0 mg/l except in the immediate vicinity of raw waste introduction where it shall not be permitted to fall below 0.5 mg/l at any time. In the event these minimum dissolved oxygen levels cannot be maintained the test shall be terminated.

4. The raw domestic waste utilized as feed for the unit shall have been passed through a 1/4 inch slot comminutor prior to entering the unit and during this phase of the test it shall be applied in a subdivision pattern as defined elsewhere in this method.
5. Daily twenty-four hour influent and effluent samples composited strictly according to the influent flow pattern shall be collected. The frequency of sampling to make up the required daily composites shall be at least once hourly.
6. The rate of flow applied to the unit under test shall be measured and recorded continuously and the volume of waste applied daily shall be totaled and reported. The total volume of waste applied to the unit daily shall be the rated capacity of the unit plus or minus five percent.
7. The daily influent and effluent composites shall be subjected to laboratory analysis to determine the following:
 - a. Five Day Biochemical Oxygen Demand (mg/l).
 - b. Suspended and volatile suspended solids (mg/l).
 - c. pH

The temperature of the influent and effluent shall be determined for both maximum and minimum flow periods.
8. At the midpoint of the maximum flow period a grab sample of the mixed liquor shall be taken as near the center of the aeration compartment as possible. A return sludge grab sample shall be taken daily at the same time, if possible. Also, at the same time the dissolved oxygen content and temperature of the aeration compartment contents in the immediate vicinity of the raw waste introduction point, middle of the compartment, and the immediate vicinity of the compartment exit shall be determined.

Both the mixed liquor and return sludge grab samples (see C-8) shall be subjected to laboratory analysis to determine the following:

- a. Suspended and volatile suspended solids (mg/l).

b. pH

- c. Thirty minute settled volume (SV₃₀, ml.) (sludge volume index computed for mixed liquor samples only).

9. As soon as the mixed liquor suspended solids value reaches 2,500 mg/l plus or minus ten percent the Startup Performance Evaluation shall be terminated and the Subdivision Flow Pattern Evaluation shall start at once without any interruption of feed to the unit or lapse of time.

D. SUBDIVISION FLOW PATTERN PERFORMANCE EVALUATION

1. The provisions of Section C, subsection 3, 4, 5, 6, and 8, shall be complied with during this phase of the evaluation.
2. The period of Subdivision Flow Pattern Performance Evaluation shall be the next consecutive thirty days following the Startup Performance Evaluation period.
3. The daily influent and effluent composite samples (see C-5) shall be subjected to laboratory analysis to determine the following:
 - a. Five Day Biochemical Oxygen Demand (mg/l, BOD₅)
 - b. Suspended and volatile suspended solids (mg/l)
 - c. pH
 - d. Methyl Orange Alkalinity (mg/l)
 - e. Ammonia-nitrogen (mg/l, NH₃-N)
 - f. Total Soluble Phosphate (mg/l, PO₄-P)
 - g. Methylene Blue Active Substance (mg/l, MBAS)
 - h. Chemical Oxygen Demand (mg/l, COD)

In addition to the above, the daily effluent composite shall also be subjected to the following analyses:

 - a. Nitrate-nitrogen (mg/l, NO₃-N)
 - b. Dissolved Oxygen (mg/l)
4. The temperature of the plant influent and the effluent shall be determined during both the maximum and minimum flow periods.

E. FLOW PATTERN CHANGE AND SOLIDS ADJUSTMENT PERIOD

1. At the end of the thirty day Subdivision Performance Evaluation period and while still maintaining the conditions of loading required during that period, the mixed

liquor suspended solids shall be adjusted to 2,500 mg/l plus or minus ten percent by wasting solids from the plant. Such wasting is to be carried out in as short a time as possible not to exceed one day.

2. Immediately following the adjustment of the mixed liquor suspended solids concentration the influent flow pattern shall be changed to that of a school as defined elsewhere in this method. The total volume of waste applied to the unit daily shall be the rated capacity of the plant plus or minus five percent.
3. Sampling shall be suspended for a period of one week during this period to permit the adjustment of solids, change of flow pattern, and the adjustment of the plant to the new conditions.

F. SCHOOL FLOW PATTERN PERFORMANCE EVALUATION

1. The provisions of Section C, subsections 3, 4, 5, 6, and 8, shall be complied with during this phase of the evaluation.
2. The provisions of Section D, subsections 3, and 4, shall also be complied with during this phase.
3. The period of School Flow Pattern Performance Evaluation shall be the next consecutive thirty days following the Flow Pattern Change and Solids Adjustment Period. The school flow pattern shall be on the basis of a five day week.

G. DEVIATIONS FROM STANDARD METHODS

1. The following deviations from the provisions of Standard Methods for the Examination of Water and Wastewater³⁷ are permitted:
 - a. The thirty minute settled volume (SV_{30}) test shall be conducted by settling a one liter volume of mixed liquor diluted with plant effluent to a suspended solids concentration of approximately 1,500 mg/l. The actual suspended solids concentration shall be determined and used in computing the sludge volume index value. A recommended alternate is the use of a larger dilute sample and a properly calibrated three

liter battery jar. These deviations apply only to Section D and F tests.

- b. Glass fiber filter mats may be used in connection with the Gooch Crucible Method for the determination of suspended solids. The use of such mats is recommended.

H. FLOW PATTERNS

The percentage of the total daily flow applied during each hour of the day shall be as follows:

Hour	Subdivision Pattern	School Pattern
12:00M - 1:00AM	1.5	0
1:00AM - 2:00AM	1.5	0
2:00AM - 3:00AM	1.5	0
3:00AM - 4:00AM	1.5	0
4:00AM - 5:00AM	2.5	0
5:00AM - 6:00AM	2.5	0
6:00AM - 7:00AM	3.0	0
7:00AM - 8:00AM	3.0	0
8:00AM - 9:00AM	4.0	12.5
9:00AM - 10:00AM	4.5	12.5
10:00AM - 11:00AM	6.5	12.5
11:00AM - 12:00N	6.5	12.5
12:00N - 1:00PM	6.5	12.5
1:00PM - 2:00PM	6.5	12.5
2:00PM - 3:00PM	4.5	12.5
3:00PM - 4:00PM	4.5	12.5
4:00PM - 5:00PM	4.5	0
5:00PM - 6:00PM	4.5	0
6:00PM - 7:00PM	5.0	0
7:00PM - 8:00PM	5.0	0
8:00PM - 9:00PM	5.0	0
9:00PM - 10:00PM	5.5	0
10:00PM - 11:00PM	5.0	0
11:00PM - 12:00M	5.0	0

IV. RESPONSIBILITIES

During the course of these studies the project committees have given considerable thought to the matter of the responsibilities of the several parties to the manufacture and use of extended aeration package sewage treatment plants. This matter of responsibilities is so intimately a part of the entire question of the use and performance of package plants that it injects itself into any serious discussion of such plants. The following are offered in an attempt to define, at least to some extent, the logical responsibilities of those involved in the design, manufacture, application, use, and supervision of package sewage treatment plants.

A. THE MANUFACTURER-SUPPLIER

1. It is the responsibility of those who manufacture, and supply package sewage treatment plants to insure the durability and workability of the plants' structure and process support equipment. It is further their responsibility to guarantee such durability and workability to the buyer-owner.
2. It is the responsibility of the manufacturer-supplier to define and warrant the overall process efficiency to be expected in connection with the treatment of a stated waste having specified characteristics excepting that such warranty is valid only so long as the responsibilities of the other parties are met by them.
3. The manufacturer-supplier should provide the services of a qualified technician who is thoroughly knowledgeable concerning the equipment and processes involved to check the installation of the plant, supervise the startup of the plant, and to instruct the buyer-owner's operator in the proper operation and maintenance of the plant. Such a qualified individual should also be supplied for a recheck of the plant after process maturity has been achieved as evidenced by a mixed liquor suspended solids concentration of 2,500 mg/l both to insure that the plant is operating properly and to further instruct the buyer-owner's operator. Technical service in addition to the above should also be provided at the owner's request and at his expense, except as any guarantee or warranty between the parties may apply.
4. If the plant is installed by the manufacturer-supplier he should guarantee such installation. If the plant is installed by others than the manufacturer-supplier he should supply the installer with adequate installation instructions.
5. The manufacturer-supplier should provide the buyer-owner at the time of plant start-up with a complete manual outlining the proper operation and maintenance procedures and including adequate drawings and descriptive literature so as to render these matters understandable to a qualified operator of such plants. This manual should also include a complete but readily understood discussion of the principles involved in the processes employed by the plant as well as a thorough description and discussion of the test methods required for the intelligent operation of such processes.
6. Also at the time of startup of the plant, the manufacturer should supply the owner with a complete replacement parts list for the plant and all of its equipment including up-to-date information on the availability of replacement parts, parts suppliers, and any known applicable substitute parts. Further, such parts list should contain a recommendation concerning the types and quantities of spare parts which the buyer-owner should maintain on hand to facilitate emergency repairs. Any unusual tools that might be required for the proper repair or maintenance of the plant and its equipment should also be brought to the owner's attention by suitable mention in the parts list or maintenance manual. The availability of replacement parts for a specified period of time should be a part of the manufacturer-supplier's warranty to the buyer-owner.
7. It should be the responsibility of the manufacturer-supplier to furnish certified copies of The Standard Performance Evaluation Method results available pertaining to the particular plant model series involved as a part of any submission of plants and/or specifications to a reviewing regulatory agency or official that may be required by law or regulation. It should be his further responsibility to provide the same information to the buyer-owner and his engineering consultant.

B. THE BUYER-OWNER

1. It is the responsibility of those who buy, own, and operate package sewage treatment plants to secure or provide the services of a competent engineer to set up specified critical flow ranges and loadings for sizing the plant within the general or specific requirements of the regulatory agencies or officials having jurisdiction, to determine plant location, and to perform related engineering services as outlined herein.

2. The owner of a package sewage treatment plant has the responsibility of providing as the plant operator a person who is conscientious, of adequate intelligence, and in good physical condition and who, therefore, is capable of learning to operate and maintain the plant within a reasonably short period of time given adequate instruction.
3. In the event the original plant operator leaves the employ of the owner it is the owner's responsibility to immediately secure a replacement for him who has the same attributes as set forth for the original operator and to provide the new operator with suitable training for the job.
4. It is the responsibility of the buyer-owner, through his engineering consultant, to secure from the agencies or officials having jurisdiction the approvals, permits, or licenses required by law or regulation for the construction and operation of the plant unless this is specifically delegated by contract to another of the parties
5. It is also the responsibility of the owner to give general supervision to his operator and to provide the operator with all necessary tools, materials, parts, and the like required for the proper operation and maintenance of the plant. It should be noted in this connection that the owner himself is ultimately responsible for the performance of the plant.
6. The owner of a package sewage treatment plant is responsible for any failure of the plant to perform as set forth in the manufacturer-supplier's warranty and/or as required by law or regulation when such failure is the result of organic and/or hydraulic loadings or waste characteristics which differ from those in the warranty. It should be further noted that the owner is, in most jurisdictions, solely responsible for any failure of the plant to perform as required by law or regulation regardless of cause.

C. THE CONSULTING-SUPERVISING ENGINEER

1. The owner's engineer is responsible for the setting of organic and hydraulic load levels to be applied to the plant and for selecting the plant(s) which in his best judgement are capable of reliably treating the waste at these loadings in such a manner as to conform with all applicable laws and regulations.
2. Not only is the engineer responsible for defining the load levels to be treated but he is further responsible for defining both

the organic and hydraulic pattern of loading and the specific characteristics of the waste to be treated. It is the additional responsibility of the engineer to fully disclose all of these characteristics, loadings, and conditions to the manufacturer-supplier and the buyer-owner as well as the regulatory agencies and officials having jurisdiction.

3. The engineer is responsible for determining the location of the plant, the design of adequate inlet and outlet sewers, the design of required auxiliary structures and appurtenances as required as well as necessary power lines and the like.
4. It is ordinarily the responsibility of the engineer to represent the buyer-owner in securing the required permits and licenses or to delegate this by contract or agreement to another of the parties.
5. It is the responsibility of the engineer to generally oversee and inspect the installation and/or construction of the plant and its appurtenances specified in the contract drawings and to require such corrections to be made by the manufacturer-supplier/installer as may be necessary in order to conform to the approved drawings and specifications.

D. THE INSTALLER-CONTRACTOR

1. In the event that an installer-contractor rather than the manufacturer-supplier installs the package sewage treatment plant, it is the responsibility of such installer-contractor to make the installation in accordance with the manufacturer-supplier's instructions.
2. It is the further responsibility of the installer-contractor to insure that good workmanship standards are maintained and that the overall process efficiency is not limited by any defect in installation.

E. THE REGULATORY AGENCY-OFFICIAL

1. In the course of the normal discharge of their duties regulatory agencies and officials having jurisdiction would carefully review all of the available information concerning the package sewage treatment plant proposed for use in each particular case. This review would include The Standard Performance Evaluation Method results which pertain to the particular plant model or model series which is being proposed. After such review it would finally be the responsibility of the agency-official to make a value judgement as to the capability of the proposed plant to treat the specific waste, in view of

the loadings and loading pattern, to the degree required in each case.

2. Following the installation of the plant the regulatory agency-official would normally make an inspection of the plant. The agency-official would require the owner to submit for review certain test results and operating reports and/or would conduct such tests and inspections as required to insure that the performance of the plant met the waste treatment requirements in each case.
3. In the event that the agency-official determined that the plant was not meeting the waste treatment requirements the owner would be required to take the necessary steps to insure the required level of treatment.

F. THE PLANT OPERATOR

1. The plant operator is responsible for the conscientious and proper operation and maintenance of the plant under the overall responsibility of the owner.
2. It is also the responsibility of the operator to make such observations and to conduct such tests as may be required for the proper operation of the processes involved in the plant, to record the results of such observations and tests, and to make these results known to the owner who, further, may be required to make them known to the regulatory agency-official.
3. The operator has the responsibility of advising the owner as to the tools, supplies, and parts which may be required from time to time for the proper operation and maintenance of the plant and to do so in sufficient time to insure that such items are available when needed.
4. It is a prime responsibility of the operator to become fully acquainted with the plant and all of its appurtenances especially including the processes involved in the treatment system and to take full advantage of

all training offered by the manufacturer-supplier, owner, and regulatory agency-official.

5. The operator is responsible for informing the owner at once of any process interruptions or observed losses of efficiency of such a nature or extent as to render the waste treatment level less than that required by law or regulation.

G. THE PERFORMANCE EVALUATION ORGANIZATION

1. It is the responsibility of the agency, group, or organization which conducts plant performance evaluations to do so strictly in accordance with the Standard Performance Evaluation Method and to certify the results of such testing to the manufacturer of the plant. In addition to the detailed test results a data summation shall be supplied.
2. Standard Performance Evaluation method data should be used by a recognized testing organization in a certification program. Such a program would make standard performance information readily available for use by those concerned in making judgment decisions regarding package sewage treatment plants.

From the foregoing seven sections on the roles and responsibilities of the various parties concerned in the design, manufacture, testing, use, and supervision of package sewage treatment plants it is clear that each of these parties influences and contributes to the final overall plant performance actually observed in the field. This is also clear from the studies and findings reported here for these findings have shown that defects in design, manufacture, application, and operation greatly influence the observed overall plant performance. In the final analysis, no one of these factors can be said to be truly more important than any other for it requires the best efforts of all concerned to achieve the desired result.

V. SUMMARY

The work reported here represents a joint effort on the part of many persons, agencies, companies, and organizations to find a means of fairly evaluating the performance of package sewage treatment plants. A large number of such plants were operated under closely controlled conditions so that those factors which influence their overall efficiency could be identified and an assessment made of the importance of each. In

brief, it can be said that the overall efficiency of extended aeration package sewage treatment plants depends upon their design, application, and operation. No one of these factors can be said to be, in the final analysis, more important than the others for it is only when a plant is designed, applied, and operated properly that the desired results are achieved.

A standard method has been presented which will give detailed information about package sewage treatment plants under conditions of startup, average loading, and severe loading. It is felt that these three conditions fairly bracket the range of conditions under which the vast majority of package sewage treatment plants must operate and that the operation of these plants under these three conditions yields data which can be used in making value judgements as to their likely performance under specific conditions. Thus, a method is provided which will assist water pollution control regulatory officials, engineers, and others concerned in the performance evaluation of extended aeration package sewage treatment plants.

It has also been shown through this study of a representative cross section of the presently available extended aeration package plants that these plants are capable of sustained, high re-

moval of applied biochemical oxygen demand when properly operated and maintained. The fundamentals of the processes and factors involved have been illustrated and discussed in detail. Rapid analytical methods have been described which have proven useful in the operation and performance evaluation of package plants and which can be used in the field by both those who operate and who supervise the operation of extended aeration plants.

Perhaps the most important contribution of all, in the final analysis, has been the demonstration of cooperative problem solving in the wastewater treatment field by all the parties who are concerned with that problem. It is believed that the same methodology which was demonstrated by the present study could well be applied in the search for answers to many other problems in this field.

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NSF Note to the Tables, pp. 50-53

The data in the tables on the following four pages constitute an appendix to the report on criteria development. The figures presented represent values determined not necessarily with all plants operated in conformance with normal loading patterns. Tables I-A, I-B and I-C present mean figures sometimes determined from a series of values too few in number to be regarded as statistically significant. Upon reexamination of influent data for the latter three tables, it is questionable whether single values should be offered or whether a range of values would give the reader a better appreciation of plant loadings. On the other hand, effluent values are based upon a much more significant number of determinations and appear to reflect quite fairly the level of discharges obtained from the plants under the patterns of operation prevailing.

It is urged that readers of the report exercise considerable restraint in using the data in the tables as a point of reference in judging the performance of any individual plant which may later be evaluated independently or by NSF.

In its testing and certification program, NSF proposes to use the following procedure to provide, on the one hand, data which will represent the performance of a given plant under test and, on the other hand, valid point of reference data which will be useful to any interested party for comparative purposes. In any given round of testing (until a substantial body of testing experience is obtained) performance data will be determined for each individual plant under test in the group, and also for the group of plants as a whole. The mean performance of each individual plant may then be validly compared, if desired, with the mean performance of the group as a whole.

NSF believes it to be important that the reader of the report clearly appreciate that the data in the tables reflects the analytical determinations carried out in the course of establishing the criteria for performance evaluation and does not in any way represent standards of performance to be attained by plants under test.

TABLE I
FALL AND WINTER STUDIES
TEN EXTENDED AERATION PACKAGE SEWAGE TREATMENT PLANTS
FULL DESIGN LOADING - STEADY STATE FLOW PATTERN
(Mean Values)

ITEM	PLANT INFLUENT	PLANT EFFLUENT
1. BOD ₅ (mg/l)	175	17
2. SS (mg/l)	190	35
3. VS (mg/l)	165	28
4. % Volatile	82	80
5. pH	7.7	7.0
6. Alkalinity (mg/l)	98	28
7. NH ₃ -N (mg/l)	18.7	6.0
8. NO ₃ -N (mg/l)		9.2
9. PO ₄ -P (Total Soluble) (mg/l)	12.0	12.0
10. Dissolved Oxygen (mg/l)		2.5
11. Methylene Blue Active Substance (mg/l)	5.0	1.2
12. % Reduction (Total Plant)		
a. BOD ₅		90
b. SS		82
c. VS		83
d. Alkalinity		71
e. NH ₃ -N		68
f. PO ₄ -P		0
g. M.B.A.S.		76
13. MLSS (mg/l)	3,100	
14. MLVSS (mg/l)	2,450	
15. % Volatile MLSS	79	
16. pH, mixed liquor	7.0	
17. SV ₃₀ (ml), mixed liquor	347	
18. Temperature, mixed liquor (°C)	11.4	
19. Dissolved Oxygen, mixed liquor	3.5	
20. Sludge Density Index	0.9	
21. BOD/SS	0.92	0.49
22. BOD/VS	1.06	0.61
23. lb. BOD ₅ /lb. MLSS		0.06
24. lb. BOD ₅ /lb. MLVSS		0.07

TABLE I-A
 SPRING AND SUMMER STUDIES
 FOUR EXTENDED AERATION PACKAGE SEWAGE TREATMENT PLANTS
 STEADY STATE FLOW PATTERN
 (mean values)

ITEM	INFLUENT	EFFLUENT	
		FULL LOAD	HALF LOAD
1. BOD ₅ (mg/l)	186	16	14
2. SS (mg/l)	216	29	30
3. VS (mg/l)	180	21	20
4. COD (mg/l)	210	32	25
5. % Volatile	83	72	67
6. pH	7.5	7.2	7.2
7. Alkalinity (mg/l)	47.0	17.8	14.5
8. NH ₃ -N (mg/l)	16.2	0	0
9. NO ₃ -N (mg/l)		14.5	17.5
10. PO ₄ -P (Total Soluble) (mg/l)	14.0	14.0	13.3
11. Dissolved Oxygen (mg/l)		2.1	2.2
12. M.B.A.S. (mg/l)	5.5	0.9	1.0
13. BOD/SS	0.86	0.54	0.47
14. BOD/VS	1.03	0.74	0.70
15. BOD/COD	0.89	0.50	0.56
16. % Reduction			
a. BOD ₅		92	92
b. SS		87	86
c. VS		89	89
d. COD		85	88
e. Alkalinity		63	69
f. NH ₃ -N		100	100
g. PO ₄ -P		0	5.0
h. M.B.A.S.		84	82
MIXED LIQUOR			
		Full Load	Half Load
17. MLSS (mg/l)		3,250	2,100
18. MLVSS (mg/l)		2,375	1,450
19. % Volatile		73	69
20. pH		7.1	7.1
21. SV ₃₀ (ml)		225	160
22. Sludge Density Index		1.49	1.32
23. Temperature (°C)		18.4	18.0
24. Dissolved Oxygen (mg/l)		3.3	2.1
25. lb. BOD/lb. MLSS		0.06	0.04
26. lb. BOD/lb. MLVSS		0.08	0.07

TABLE I-B
 SPRING AND SUMMER STUDIES
 FOUR EXTENDED AERATION PACKAGE SEWAGE TREATMENT PLANTS
 SUBDIVISION FLOW PATTERN
 (mean values)

ITEM	INFLUENT	EFFLUENT	
		FULL LOAD	HALF LOAD
1. BOD ₅ (mg/l)	198	20	10
2. SS (mg/l)	234	36	32
3. VS (mg/l)	192	26	22
4. COD (mg/l)	220	32	18
5. % Volatile	82	72	69
6. pH	7.5	7.1	7.2
7. Alkalinity (mg/l)	48.0	19.5	14.2
8. NH ₃ -N (mg/l)	17.4	0	0
9. NO ₃ -N (mg/l)		15.3	20.0
10. PO ₄ -P (Total Soluble) (mg/l)	11.3	11.3	10.3
11. Dissolved Oxygen (mg/l)		1.6	2.2
12. M,B,A,S. (mg/l)	6.1	0.8	0.9
13. BOD/SS	0.85	0.56	0.31
14. BOD/VS	1.03	0.77	0.45
15. BOD/COD	0.90	0.63	0.56
16. % Reduction			
a. BOD ₅		90	95
b. SS		85	86
c. VS		86	89
d. COD		85	92
e. Alkalinity		59	71
f. NH ₃ -N		100	100
g. PO ₄ -P		0	8.8
h. M,B,A,S.		87	85
Mixed Liquor			
		Full Load	Half Load
17. MLSS (mg/l)		4,330	3,050
18. MLVSS (mg/l)		3,120	2,130
19. % Volatile		72	70
20. pH		7.3	6.9
21. SV ₃₀ (ml)		6.0	2.85
22. Sludge Density Index		0.67	1.07
23. Temperature (°C)		18.6	18.2
24. Dissolved Oxygen (mg/l)		2.0	3.0
25. lb. BOD ₅ /lb. MLSS		0.05	0.03
26. lb. BOD ₅ /lb. MLVSS		0.06	0.05

TABLE I-C
 SPRING AND SUMMER STUDIES
 FOUR EXTENDED AERATION PACKAGE SEWAGE TREATMENT PLANTS
 SCHOOL FLOW PATTERN
 (mean values)

ITEM	INFLUENT	EFFLUENT	
		FULL LOAD	HALF LOAD
1. BOD ₅ (mg/l)	210	38	20
2. SS (mg/l)	240	63	48
3. VS (mg/l)	198	44	30
4. COD (mg/l)	243	53	40
5. % Volatile	83	70	62
6. pH	7.5	7.3	7.3
7. Alkalinity (mg/l)	50.0	26.0	16.0
8. NH ₃ -N (mg/l)	18.6	3.6	0.5
9. NO ₃ -N (mg/l)		8.0	20.8
10. PO ₄ -P (Total Soluble) (mg/l)	12.3	11.7	11.7
11. Dissolved Oxygen (mg/l)		1.1	2.2
12. M.B.A.S. (mg/l)	6.8	1.2	1.0
13. BOD/SS	0.87	0.60	0.42
14. BOD/VS	1.06	0.86	0.67
15. BOD/COD	0.86	0.72	0.50
16. % Reduction			
a. BOD ₅		82	90
b. SS		74	80
c. VS		78	85
d. Volatile		78	84
e. Alkalinity		48	68
f. NH ₃ -N		81	98
g. PO ₄ -P		4.9	4.9
h. M.B.A.S.		82	85
		Mixed Liquor	
		Full Load	Half Load
17. MLSS (mg/l)		2,450	2,080
18. MLVSS (mg/l)		1,750	1,290
19. % Volatile		71	62
20. pH		7.2	7.3
21. SV ₃₀ (ml)		124	150
22. Sludge Density Index		1.97	1.39
23. Temperature (°C)		21.0	23.3
24. Dissolved Oxygen (mg/l)		1.0	2.4
25. lb. BOD/lb. MLSS		0.09	0.05
26. lb. BOD/lb. MLVSS		0.12	0.08